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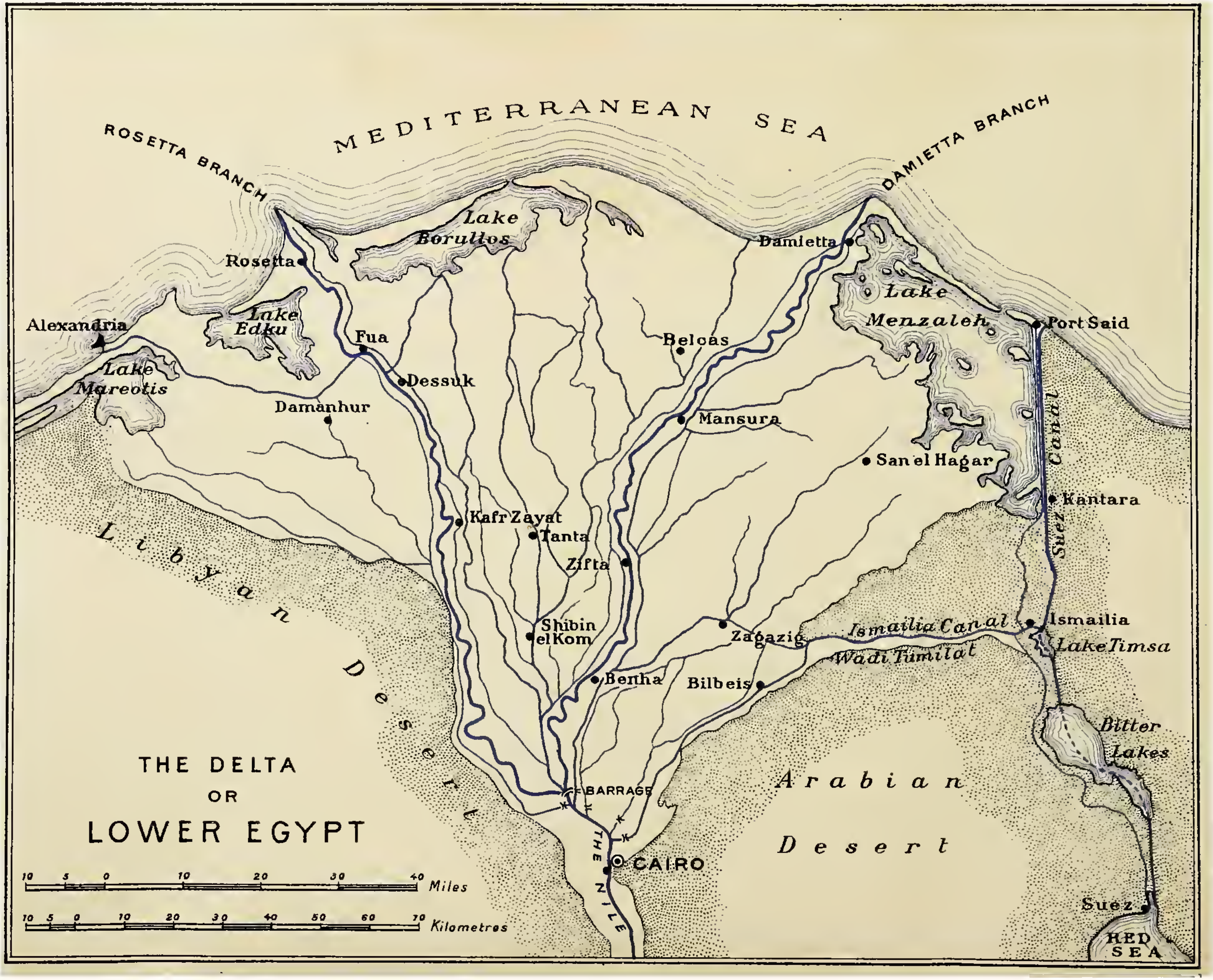
# THE DELTA BARRAGE



THE DELTA
OR
LOWER EGYPT

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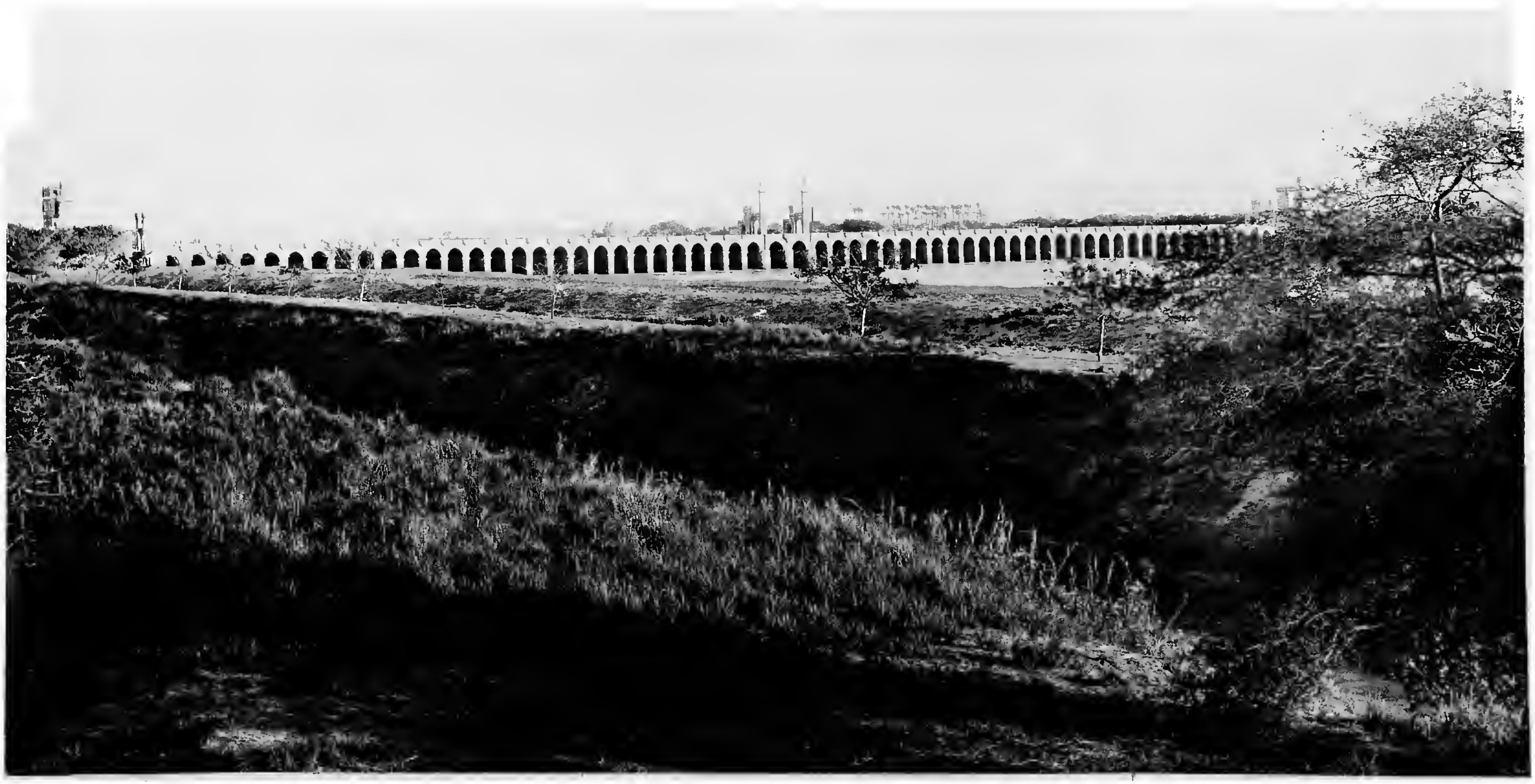

THE ROSETTA BARRAGE. VIEW FROM DOWN STREAM

# THE

# DELTA BARRAGE

# OF

# LOWER EGYPT

BY

MAJOR R. H. BROWN, C.M.G., (LATE R.E.)

*WITH AN INTRODUCTION BY*

SIR WILLIAM GARSTIN, K.C.M.G.,

UNDER SECRETARY OF STATE FOR PUBLIC WORKS, EGYPT.

> " Better is the end of a thing
> than the beginning thereof."
> ECCLESIASTES, vii, 8.

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"Son of man, say unto Pharaoh, king of Egypt, and to his multitude; whom art thou like in thy greatness? Behold, the Assyrian was a cedar in Lebanon with fair branches, and with a shadowing shroud, and of an high stature; and his top was among the thick boughs. The waters nourished him, the deep made him to grow: her rivers ran about her plantation; and she sent out her channels unto all the trees of the field. Therefore his stature was exalted above all the trees of the field; and his boughs were multiplied, and his branches became long by reason of many waters, when he shot them forth. **** Thus was he fair in his greatness, in the length of his branches: for his root was by many waters."

EZEKIEL, xxxi, 2-5, and 7. R. V.

# AUTHOR'S PREFACE.

Some years ago I published in Cairo, under the title of *"History of the Barrage," all the information I had been able to collect about the great irrigation Work at the head of the Delta of Egypt. That record ended with July 1896. Since then, it is no longer sufficient to speak of the subject of this book as "The Barrage," for a rival has grown almost to full stature at Assiout. I have, therefore, entitled it—"The Delta Barrage." It is known to the Arabs as "Foum el Bahr," the Mouth of the River, or "Kanatir el Khaïriyah," the Bridges of Welfare.

Since July 1896 also, important operations for the further strengthening of the foundations of the Barrage itself have been carried out, and subsidiary weirs have been built a short distance below it, with the object of not only relieving the original work of some of the strain it was called upon to bear, but also of increasing its utility by enabling it to get more work out of the river supply. The first part of this account is to a great extent a repetition of the earlier publication, but the latter part deals with more recent history, bringing the record up to date.

The life history of the Barrage is no common engineering biography. It is a history with a moral, and should be accepted by all concerned with hydraulic work as a warning to be careful that there is nothing scamped below water and out of sight: for, as soon as the test of active service comes, water, according to the laws of its nature, will

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* *History of the Barrage*, pub. F. Diemer, Cairo.

search for the weak spot, and the scamping will be found out. The deceptive massiveness of an imposing superstructure will avail nothing.

An American gentleman, who, not long ago, used to haunt Cairo regularly in the winter, and who was famous for his power of sustaining conversation single handed beyond the ordinary limits, amused himself at times by entertaining his listeners with some interesting particulars about a Countess with a romantic name that has escaped my memory. This lady, he explained, had an elliptical soul with an orbit of 5,800 years or thereabouts. The eccentric and the elliptical orbits intersected in Paris about the year 1890 A.D.; and the American gentleman learnt from his friend, the Countess, that, during her previous existence on this planet, about 3,900 B.C., she was present at the building of the Pyramids; so that she was able to affirm that they were constructed "from the top downwards and from the inside outwards." Now, it is not my business to explain this dark saying as applied to the Pyramids; but I have recalled what a reputed eye-witness had to say of the manner of building them, as it appears that the description of the process applies to the manner of building the Barrage. For, after 1861, when the work was supposed to be finished, it was found, by the many experts who examined it, to have a superstructure of sound make, but an underlying platform so defective as to be practically no foundation at all. And so it came about that the superstructure, years after it was built, was given secure foundations by forming an upper and enveloping layer of sound masonry over and beyond the defective material of the original attempt at a substructure; and that, later still, the loose material below was compacted together from within by cement-grout. So that we have first a sound superstructure resting on insecure foundations: then a sound upper layer is added over the defective floor: and lastly the substructure that was defective, is rendered sound by the introduction of a cementing material for the want of which the floor had no right at all to be considered foundations. And, moreover, the cement grout was introduced from the top downwards and worked its way from the inside outwards ,for it was poured down internal bores from the very top of the finished work to the underside of the lowest lying stratum of the foundations to work its way outwards in all directions from the bottom of the bore between the loose particles of the disintegrated concrete that all above was built upon.

It is not to be expected that a work on such a subject as the Barrage can be made sufficiently light for the particular variety of Egypt's visitors whose mental digestion is upset by all descriptions of solid food. By such the Barrage will be looked upon as a pleasant spot for a day's picnic and that is all.

A primrose by the river's brim,
A yellow primrose was to him,—
And it was nothing more.

But there are residents in Egypt, and a different variety of visitors, who take an intelligent interest in all that makes for the well-being of the country, and who do not limit their attention to the Monuments of the Past and the teaching of the Guide Books. It is a matter of taste: some find their pleasure in Zoological Gardens and Agricultural Shows; others in fossil collections and relics of the Palæolithic. I have hopes that those with a living interest may read this account and take pleasure therein, or at least may learn something they did not know before.

Even the Sphinx—its personal connection with the most remote past notwithstanding—turns its back on the royal tombs and the lifeless desert to gaze across green fields and flowing river towards the city of the living, the source from which the annual flood of ever-changing travellers streams to look upon its face that changeth not. So has Kinglake's fancy, when painting his prophetic picture of the

Egypt that was to be, on the canvas of his Eothen, endowed the Sphinx with a living interest, in words that most have read :—

"And we, we shall die, **** and the Englishman, leaning far over to hold his loved India, will plant a firm foot on the banks of the Nile, **** and still that sleepless rock will lie watching, and watching the works of the new busy race, with those same sad, earnest eyes, and the same tranquil mien everlasting."

There is an old fable of the Sphinx that tells how she sat by the wayside, propounding her riddles to the passers by, and dealing out death to those that could not answer. Egypt's Sphinx has—and has ever had—a riddle for the people of the land of the Nile, and on their answer to it hangs the life of their country. "Answer her riddle, it is well with thee; answer it not, pass on regarding it not, it will answer itself: the solution for thee is a thing of teeth and claws"*—the Father of terror, 'Abu el Hol' of the Arabs. But the riddle of the Egyptian Sphinx is not a difficult one to read. King Menes of tradition and the Amenemhats and Usertesens of monumental history answered the riddle in deeds; and so also, in later days, Mehemet Ali. And later still, one who had the 'seeing eye' and knew Egypt well put the answer into words when he proclaimed that "Irrigation is the Egyptian Question."

* CARLYLE, "Past and Present."

The works, from which extracts, often literal and lengthy, have been made, and illustrations borrowed, are the following:—

*Mémoires sur les Principaux Travaux d'Utilité Publique en Égypte*, par LINANT DE BELLEFONDS BEY.

*L'Égypte, son Avenir Agricole et Financier*, par FÉLIX PAPONOT.

*Note on the Barrage*, by SIR COLIN SCOTT MONCRIEFF, K.C.M.G., C.S.I.

*Irrigation in Egypt*, by SIR COLIN SCOTT MONCRIEFF, Professional Papers of R.E., vol. xix.

*Egyptian Irrigation*, by W. WILLCOCKS, C.M.G., M.I.C.E.

*Annual Irrigation Reports*, Egypt, from 1884 to 1900.

Manuscripts in the Khedivial Library, Public Works Ministry, Cairo.

# CONTENTS.

## CHAPTER I.

PAGE.
History of the Barrage previous to 1884 . . . . . . . . . . 1

## CHAPTER II.

Description of the Barrage and its Object . . . . . . . . 25

## CHAPTER III.

History of the Barrage from 1884 to 1894 . . . . . . . . 31

## CHAPTER IV.

Cement-grouting operations for further security of the Barrage Foundations . . . . . . . . . . . . . . . . . 44

## CHAPTER V.

Subsidiary Weirs below the Barrages . . . . . . . . . 51

## CHAPTER VI.

Work done by the Barrage . . . . . . . . . . . . 66

# LIST OF ILLUSTRATIONS.

PAGE
Map of the Delta of Egypt.
Frontispiece.—The Rosetta Branch Barrage. Photograph.
Plate I.—Part of Linant's Map . . . . . . . . . . . . . . 10
Fig. 1.—Section of Rosetta Barrage . . . . . . . . . . . . 11
Fig. 2.—Section of river bed at site of Rosetta Barrage . . . . . . . 12
Figs. 3 and 4.—Sections and plans of original construction . . . . . . 13
Figs. 5 and 6.—Sections and plans of original construction . . . . . 14
Plate II.—Linant's record plan of 1853 . . . . . . . . . . . 16
Plate III.—Bridge over fort ditch. Photograph . . . . . . . . 17
Plate IV.—Parapet wall of Rosetta Barrage. Photograph . . . . 18
Plate V.—Sir John Fowler's proposal . . . . . . . . . . . 20
Plate VI.—River and Canals at the Barrage . . . . . . . . . 23
Plate VII.—Binding the lands of the Nile. Photograph . . . . . 25
Plate VIII.—The Barrage as originally built . . . . . . . . . 29
Fig. 7.—Diagram to show loose stone bar on floor. . . . . . . . 33
Fig. 8.—Plan of ring bank . . . . . . . . . . . . . . . 35
Plate IX.—Type section for barrage additions . . . . . . . . . 36
Fig. 9.—Diagram to show action of springs . . . . . . . . . . 36
Fig. 10.—Cross-sections of work as carried out . . . . . . . . . 37
Plate X.—Rosetta Barrage during restoration, from tower. Photograph . 39
Plate XI.—Rosetta Barrage during restoration, from below. Photograph 39
Plate XII.—Clay Apron of Damietta Barrage . . . . . . . . . 41
Plate XIII.—Talus, Damietta Barrage. Photograph . . . . . . . 42
Plate XIV.—Talus, Rosetta Barrage. Photograph . . . . . . . . 42
Plate XV.—View in the Barrage Gardens. Photograph . . . . . . 45
Plate XVI.—Diagram showing bores in the piers . . . . . . . . 47
Plate XVII.—Diagram to show the object of the Weirs . . . . . . 53
Plate XVIII.—First season's work on Damietta Weir. Photograph. . 55
Plate XIX.—Cross-sections of Weirs . . . . . . . . . . . 55
Plate XX.—Second season's work on Damietta Weir. Photograph . . 57
Plate XXI.—Rosetta Weir under construction, from east end. Photo. . 57
Plate XXII.—Rosetta Weir under construction, from west end. Photo . 59
Plate XXIII.—Apparatus for forming blocks in deep trench . . . . 59
Plate XXIV.—Apparatus for forming blocks of footing wall . . . . 59
Plate XXV.—Section of Weir lock foundations . . . . . . . . 60
Plate XXVI.—Rosetta Weir on 4th June, 1900. Photograph . . . 62
Plate XXVII.—Rosetta Weir on 22nd July, 1900. Photograph. . . 64

# INTRODUCTION.

Writing in 1895, in my introduction to Major Brown's first history of the Barrage, I expressed the hope that this structure would eventually form a portion of a great system of similar irrigation works, by which the southern provinces of the Nile Valley should profit equally with those of the Delta. I scarcely realised at the time how speedily this hope would be fulfilled.

In the short space of six years, several important steps have been taken in the direction of an improved regulation of the Nile.

The works in connection with the consolidation of the Barrage have, as Major Brown's present account explains, been terminated. The construction of the great dam at Assouan, whereby the river water will be impounded above the First Cataract, has been so far advanced that its completion may be confidently anticipated in the course of next year. The important weir at Assiout, by means of which the increased supply of water derived from the Reservoir will be distributed throughout Middle Egypt, is in an equally forward state of progress. The remodelling of the existing canal system, necessitated by the transformation of the Basins into perennially irrigated tracts, is being vigorously proceeded with. At Ziftah, on the Damietta Branch, a Barrage, similar in design to that at Assiout, has been commenced during the present year. A detailed survey of the Nile Valley, south of the Second Cataract, has been started, with the object of ascertaining whether the construction of a second storage reservoir is feasible in that region. The great "Sadd," on the upper reaches of the White Nile, has been removed, and the question of minimising the waste of water which at present takes place, in the immense swamps adjoining the "Bahr-el-Gebel," is engaging serious attention, a preliminary study of this river, as far south as Gondokoro, has been made, and the results, which include a series of discharge observations, have been published in a printed Report.* Gauges have been erected at selected points on the Victoria Nyanza Lake, the Blue and the White Niles, and daily registers of the water-levels are forwarded to Cairo. Lastly, our knowledge of the general conditions which regulate the annual rise and fall of the most remarkable river in the world, has been largely increased.

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* Foreign Office Blue-book. Egypt No. 2 (1901).

The above must, I think, be allowed to be a creditable record of progress. I am fully aware that all that has hitherto been accomplished amounts to little more than a beginning, and that each increase to our stock of information regarding the Hydrology of the Nile only proves to us how little we as yet really know, and how vast are the many problems which still await solution. Nevertheless, it appears not unreasonable to predict that, if a similar rate of progress be maintained in the future, it will not be very long before the veil which guards the secrets of this great river is entirely lifted, and its complete control, from the Equator to the Mediterranean, becomes an accomplished fact.

It is, however, with the past, rather than with the future, that this note is immediately concerned, more especially with the first of the works alluded to, viz., the Delta Barrage. Major Brown rightly insists upon the importance of the part which this Barrage has played, and must always play, in the history of Egyptian Irrigation. On this point there can be no two opinions. The rich basin-lands of Upper Egypt are of great value, and it is possible that the alluvial plains of the Soudan may one day contribute to the prosperity of the Nile Valley as a whole, but the fertile Provinces which border the Deltaic branches of this river must always constitute the source from which the agricultural wealth of Egypt is mainly derived, and must always therefore possess an importance which other tracts may rival, but can never surpass.

The Provinces in question are absolutely dependent upon the Barrage for their existence. Without its assistance large portions of their cultivated area would speedily relapse into their original state of infertility. It is not then wonderful that, ever since the genius of Mougel Bey endowed Northern Egypt with such a precious gift, constant efforts should have been made to preserve this great work, which constitutes the pivot, so to speak, upon which the entire irrigation system of Lower Egypt revolves. Major Brown's present history describes these efforts, and brings the relation of success and failure up to the present time. His account is so lucid, and is given in such detail, that any words of mine must be almost superfluous.

When, in 1896, the consolidation of the Barrage was commenced, the eventual extent of the work was hardly at the time foreseen. It was originally intended to experiment upon certain of the piers only, but by degrees these experiments developed, and it was finally decided to apply the system of "cement-grouting" to the entire work. In less than four years time the foundation of each one of the 120 piers which support the superstructure has been strengthened, by forcing liquid cement, under pressure, into every crevice and cavity of the masonry. The abutments and lock-walls have been similarly treated. Some idea of the amount of work done may be gathered from the fact that the total length of the vertical holes which were bored through the solid masonry, from the roadway down to the river bed, attains to nearly eight miles.

At the same time, another and equally important development of the consolidation works was commenced in the shape of two subsidiary weirs, one in either branch of the river, downstream of the existing work. Their object is to divide the head of water thrown upon the Barrage at times of greatest pressure, and thus proportionately diminish the strain upon the structure.

Major Brown gives a clear description of these works, explaining his remarks by excellent illustrations. Even the non-technical reader should have little difficulty in understanding his meaning.

As if by coincidence, the year (1900), in which these weirs were practically completed, was characterised by an exceptionally low summer supply of water ; lower in fact than any previously recorded by the existing registers of the Nile. The gravest fears were entertained that the volume of water in the river would be insufficient to ensure the safety of even a moderate proportion of the valuable cotton crop. As the summer advanced and the fall in the water-levels continued, these apprehensions gathered in intensity, notwithstanding the special measures instituted to ensure an equitable distribution of the available water. Throughout this period, the construction of the weirs was energetically proceeded with, in the hope that, when the critical moment should arrive and the demand for water reach its maximum, they should be able to render assistance.

It was felt by all that, unless it were then possible to take full advantage of the arrival of the early flood-water and so increase the supply in the canals, the chance of saving the entire cotton crop was almost a hopeless one, and that under such circumstances the maize-sowing must be very seriously retarded.

Thanks to Major Brown's exertions, by the middle of July, these weirs were so far advanced that it was found possible to make temporary use of them, by holding up water upon them and thus reducing the head upon the Barrage; at the same time raising the upstream water-level to a height that might otherwise have endangered the stability of the structure. In the first year of their existence therefore, and before they were completely finished, these weirs rendered invaluable assistance to the country by saving both the cotton and the maize crop of Lower Egypt. This fact alone would fully justify the expenditure which their construction has involved.

Major Brown, in discussing this work, is naturally debarred from alluding to his own share in the successful results obtained. What this share has been, may be guessed by those who read this book, but I take great pleasure in the opportunity here afforded me of recording the services which he has rendered to Egypt in connection with the Barrage.

The history of this structure may be divided into three great periods :—

First ; its construction by Mougel Bey.

Second ; its restoration by Sir Colin Scott Moncrieff and Colonel Western.

Third ; Its consolidation by Major Brown.

To the names associated with each of these periods belongs their special meed of praise.

To Mougel Bey is due the credit of designing and constructing such a work — to Sir Colin Scott Moncrieff and to Colonel Western, that of restoring it, and thus enabling it to fulfil the purpose for which it was originally intended — to Major Brown, that of further developing the work commenced in the second period and thus rendering possible a striking extension of the functions of the structure. There are other names which deserve mention in any account of the Barrage ; notably those of Messrs Willcocks, Reid and Foster. The share that each has had in the work, however, has been done full justice to by Major Brown in his present history.

In conclusion, I consider that all those, who for seventeen years have been associated with the work of preserving and restoring the Barrage, have good reason to be proud of the results of their labour. I feel convinced that all who read the story which Major Brown tells in this book will share my opinion.

It is a tale of constant hard work and of constant anxiety. When I state that the yield of the cotton crop between the years 1890 and 1900 has amounted to over 58,000,000 kantars, equivalent, at a very moderate estimate, to a money value of ₤.100,000,000, I think it is conclusively proved that the work done and the sums expended upon the Barrage have produced no contemptible return.

W. E. GARSTIN,
UNDER SECRETARY OF STATE FOR PUBLIC WORKS IN EGYPT.

Cairo, 28th November, 1901.

# THE DELTA BARRAGE OF LOWER EGYPT.

## CHAPTER I.

### History of the Barrage previous to 1884.

THE "Father of History" has been quoted often enough to make it safe to assume that it is now common knowledge that the Nile has been the creative agency by which the land of Egypt has been evolved, and is the giver of life by which it is sustained. But there are physical conditions which limit its power of sustaining life; and those conditions are that the relative levels of land and water shall be such that the water may flow over the surface of the land. Such conditions exist naturally at certain times and in certain places. Where they do not naturally exist, there is no active life, unless the necessary conditions are produced artificially by lifting machinery, or by engineering works designed to raise the water-level above its natural height. The lifeless plain of Komombos, where flowing water has first laid down the soil and afterwards cut a channel deeply through it, is an instance of the absence of the necessary conditions, both natural and artificial; and here life is dormant or extinct, and the wide plain is barren: the earth brings forth no grass or herb yielding seed, and no man is found to till the ground, for rain never falls upon the earth to water the face of the ground, and the river flows past far below.

On the other hand, the land of Upper Egypt, during a flood season of ordinary height, is an instance in which the necessary conditions of life are naturally fulfilled; although, in these latter days, the natural conditions have to a great extent been modified by the introduction of artificial control.

But the Delta of Egypt is the instance with which we are concerned. Here, the artificial conditions of both descriptions—lifting machinery and engineering works—have been developed and are being developed to intensify life to the utmost. And of all the means employed to this end, the Delta Barrage is the most important and efficient: there is no other work in Egypt on which so much depends. The following pages tell of its growth, its early failures, its later successes and of present faith in its future performances.

It is recorded by Clot Bey that Napoleon Bonaparte, when in Egypt in 1798 and 1799 during the French occupation, foresaw the construction of a Barrage at the head of the Delta to control the distribution of water in the two branches of the Nile; and that he gave expression to his anticipations of the future in the following words:—

"Un jour viendra où l'on entreprendra un travail d'établissement de digues barrant les branches de Damiette et de Rosette au ventre de la vache, ce qui, moyennant des batardeaux, permettra de laisser passer successivement toutes les eaux du Nil dans une branche ou dans l'autre et de doubler ainsi l'inondation."

The day that Napoleon is said to have foreseen soon came in the reign of Mehemet Ali, who became Viceroy of Egypt in 1805. Being a man of energetic action, he lost no time in introducing a period of activity in irrigation works. The unpaid labour of the Corvée was his instrument for carrying them out; and his power to employ it was limited by no financial control, as the human labour was not converted into its money equivalent, and works executed by the Corvée were reckoned to have cost nothing!

At the commencement of his reign, Lower, as well as Upper Egypt, was irrigated under the basin system, that is, by inundation, and depended on the height of the flood for its water-supply. Too low a Nile would leave unfavourably situated lands without inundation; and hence the idea, that had suggested itself to the mind of Napoleon, of a Barrage for obtaining such control over the river that a flood, which was a low one in the united Nile above its bifurcation, could be made a high one in each branch of Lower Egypt alternately, by adopting, as it were, the military principle of concentrating one's forces in succession on the separated parts of an enemy's army, and defeating them in detail.

The development of cotton cultivation on a large scale in Lower Egypt during Mehemet Ali's reign necessitated a radical change in the whole canal system. Under the basin system winter crops, such as wheat, barley, beans and clover, were grown on the lands from which the Nile flood had retired after inundating them. But cotton cannot be grown under these conditions, for it requires to be protected from inundation, and also to be planted and irrigated before the Nile begins to rise. Hence it became necessary to embank the branches of the river for the protection of the cotton cultivation from inundation, and to dig deep canals to conduct the low level waters of the summer Nile to the neighbourhood of the crops to be irrigated. The water, being so much within soil, had, during the low Nile season, to be lifted on to the land by pumps, sakyas or shadufs. To make and maintain the Nile banks so as to be capable of resisting high floods, and to dig and keep clear the canals so that they should be deep enough to flow at low Nile, was a task that fell heavily on the country, which had to furnish the means of carrying out the work in the form of unpaid labour. Linant Pasha calculated that the quantity of work necessary for the effective clearance of the canals alone, (without taking into account the maintenance of the Nile banks,) would have come to over 13 million cubic metres a year, requiring an army of 27,404 men working for 100 days to execute it. Such a clumsy system was unable to produce the results desired, though the taskmasters did not fail through tender-heartedness to make the lives of the labourers bitter with hard bondage in those days when the "Koorbash" was still a recognised and a favourite instrument of government.

So it became necessary to devise some more scientific method for obtaining and distributing water. The configuration of the Delta naturally suggested the construction, across the heads of the two branches of the Nile, of Barrages or Regulators, which would raise the low level of the summer Nile by such an amount that water would flow into the canals, taking off from above the regulators, at so high a level that it would not be necessary to clear the beds to a greater depth below country surface than was reasonable and practicable.

But, before such a project took shape, Mehemet Ali had, in 1833, boldly commenced operations for increasing the Damietta supply at the expense of the Rosetta. The water levels of the Damietta Branch being always higher than those of the Rosetta, the irrigation of the part of the Delta which lies between the two branches, as well as the part on the east of the Damietta branch, was carried on almost entirely from canals taking off the last-named branch. Therefore, to obtain more water during summer in those canals which served as perennial canals for the Central and Eastern Delta, Mehemet Ali, with but little consideration for Behera Province and regardless of the water supply of Alexandria, proposed to dam the Rosetta Branch by a bank of loose stone, and so to divert all the water into the Damietta Branch. The idea was a bold one, but this is the only complimentary epithet that can be applied to it. If the project had been persevered with, it would probably not have succeeded; which would have been a matter for congratulation, as success would have had more unsatisfactory results than failure.

The work of damming the Rosetta Branch at Koratayn had actually been begun, when Linant Bey (afterwards Linant Pasha), then in charge of the irrigation of Upper Egypt, arrived from the South. He at once pointed out the probable consequences of such a violent interference with natural arrangements, and proposed the construction, across the head of each branch, of a Regulating Barrage designed to give command over the distribution of the water between the two branches in summer, and to leave a free passage for the river during the flood season. Whereupon, with nothing but the bare proposal before him, Mehemet Ali, with characteristic impetuosity, forthwith ordered M. Linant to proceed at once with the collection of the materials necessary to carry out his proposals, after going through the form of submitting a note to the "Grand Conseil." M. Linant was then pressed by the members of the Council to state what materials were necessary, and, in order to satisfy their impatience, he gave a figure of the quantity of ashlar, rubble stone and lime required, asking that a Commission might be appointed to study the whole subject.

At this stage Mehemet Ali, with his mind excited by the Barrage project and more impatient than his Council, proposed to M. Linant to dismantle the Gizeh Pyramids in order to utilise the stone from them in the construction of the Barrages. This proposal connected *"Pyramids and Progress" in a more direct way, but in a less admirable manner, than is attempted in Mr. John Ward's splendidly illustrated work of that title. M. Linant, knowing how to deal with his master—as an Irishman knows how to persuade his pig to move in the right direction—did not oppose the idea as an unparalleled act of vandalism,

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* *Pyramids and Progress*, by JOHN WARD, F.S.A.

but proceeded to prepare a project for the demolition. Surrounded by the halo of a Commission, composed of the Ministers of Foreign Affairs, Public Works and Public Instruction, he went to the Pyramids, and prepared his project for the demolition, according to his own account conscientiously, leaving it to his master to work out his own conclusions. Whether the details of the project were controlled by a scrupulous conscience, or were affected by an irrepressible bias in favour of the continued existence of the Pyramids, the final result of the calculations convinced the Viceroy that it would be more economical to obtain stone direct from the quarries than from the Pyramids: and so he was turned from his purpose, and the Pyramids remain to this day to grow yet older.

But the salvation of the Pyramids was probably not so much due to motives of economy on the part of the Viceroy, as to the tact with which M. Linant dealt with the danger. This view is supported by the following account of an incident which had a very different ending, and showed that the diplomatist, who in this case argued the point with the Viceroy, had less diplomacy than the Engineer who championed the Pyramids. The account is found in "A Short Memoir of Mohammed Ali," written by Sir Charles Murray whilst H. M. Consul-General in Egypt 1846-57, and edited in 1898 by Sir Herbert Maxwell. "He (Mohammed Ali) had despised and scoffed at all obstacles so long, he had overcome so many, that he at last found a pleasing excitement in them. He would sometimes undertake a thing, not because he cared about it nor that it was of the smallest utility, but merely because it was troublesome. Thus on one occasion he asked the representative of a foreign power to purchase him a steamer to navigate the Nile above the cataracts. The diplomatist in astonishment pointed out to him that there was neither wood nor coal to be had there, nor would there be any passengers or traffic. He urged, therefore, that such a project would be as costly as worthless. Moreover, there was the difficulty of transporting the boilers and machinery over rocks and whirlpools. The despot, conscious of his absolute power over three millions of subjects, confidently replied that he would have them taken to pieces and carried by thousands of men. A warm discussion took place, and the diplomatist urged at last that the scheme would cost at least 100,000 francs. On this argument, however, being used, the Pasha lost all patience, and jumping up suddenly from the sofa (a way he had when much excited) he thundered out—'Pray, sir, what the devil is it to you if it costs me a million.'"

Meantime, while the fate of the Pyramids was in suspense, the Commission, which M. Linant asked might be called together to study the project of the Barrage, was formed of members representing a charming variety of assorted talent. The Commission was composed of an architect, the Chief Engineer of the Delta, the Director of the School of Engineering, and a retired boatman in the confidence of the Viceroy, all of the foregoing being Egyptians. To these were added two English engineers, a foreign engineer who had studied in England, two French Commandants of Artillery and a French mining engineer.

This commission divided into two camps in favour of different projects. It is a wonder it did not divide into more. The one camp advocated the construction of a solid dam or weir with fixed height of crest, on each branch of the Nile, at Digwa on the Damietta Branch and at Beni Salama on the Rosetta. It was proposed in this scheme that the flood should pass *over* the dam, and also through a large opening at each end of it, which would be opened in the flood season and be kept closed during summer, on the principle of the anicuts with their under-sluices, as constructed in India. The English element in the Commission gave its support to this project, not improbably influenced in its favour by what they had learnt had been done with success in India, where, however, the conditions were different. It was urged as an objection to the adoption of such a form of dam in Egypt that it would be difficult to raise the *summer* level of the river to the extent desirable by such a permanent obstruction without raising the *flood* level to an undesirable extent up-stream, and as a result (in the case of the Delta Barrage), inundating Cairo and much else. Further, it was argued that the power of distributing the water in summer, in varying proportions at will between the two branches, would not be obtained by such an arrangement.

In connection with this proposal it is interesting to note that, when, in later years, the question of restoring the unsound Barrage was under consideration, Mr. Willcocks made a proposal to remove *all* the piers and to raise the floor permanently 2·50 metres: on the top of this floor he proposed to add movable drop gates 1·50 metres high.

He maintained that a solid wall, 2·50 metres high, would not obstruct more of a *high* flood than the present piers do. But, though this would have been creating a solid immovable dam or weir, such a weir would not have had a *fixed* crest, as the gates of 1·50 metres height would have been made use of for raising the summer level to the extent desirable, while at the same time the fixed obstruction would not have raised the flood level to an extent greater than the existing Barrage does.

The alternative project, favoured by M. Linant and the rest of the Commission, was to construct open Barrages across the two branches as near as possible to the head of the Delta, then at Derawi; the Rosetta Branch Barrage to be situated at Kafr-Mansour, and the Damietta Branch Barrage below Derawi, at both which sites the bends of the river favoured such a disposition of the works. These two Barrages were, according to this project, to be regulators capable of raising, during summer, the water level up-stream of them to the height required to supply the three main canals which were destined to irrigate nearly all Lower Egypt. During the time of flood the regulating apparatus was to be removed, so that the river might be given a free passage through the Barrage, and not be headed up. Thus the object of the work differed from the original Napoleonic idea, which, if correctly recorded, contemplated manipulating a deficient flood, and not the summer supply. The estimated cost of these Barrages was £E.1,551,633, and it was calculated that they would take five years to construct.

This project of Linant's, which was undoubtedly the more suitable one, received the Viceroy's approval, and the excavation for the work was begun forthwith towards the end of 1833 by means of Corvée labour, the men being sent on to the work by the orders of the Viceroy in such numbers as to cause considerable embarrassment to those in charge of the work. But in spite of the confusion that overcrowding produced (and only those who have worked with Egyptian labourers can appreciate what that means), a start was made, and work went on fairly well, until in 1835 the plague, that Kinglake describes in "Eothen," visited the works and made itself master there for four months, during which period the works were suspended. Still, the preparation of the project progressed, so that, in July 1835, M. Linant was able to present to the Viceroy the designs and estimates of the

Barrages complete, and to get them accepted. By this time the plague had left. But the work itself seems to have been stricken by the pest, for it languished as one doomed to die. The numbers of the labourers dwindled, materials ceased to arrive, and M. Linant himself, now no longer occupied in attending to the construction of the Barrages, was called in 1837 to the Ministry to direct the Public Works Department.

The Viceregal interest would have been capable of reviving the spent energy, but His Highness Mehemet Ali had grown tired of the Barrages, and from being impetuous had grown lukewarm. In this state of mind he appointed a Commission of sixteen members to examine the question of the desirability of such constructions. To this Commission his view, that Barrages were not necessary, was plainly enough indicated to guide a subservient Commission to conclusions in agreement with His Highness's views. But the Commission did not take the hint, though so plainly given, and declared decidedly in favour of Barrages as proposed by M. Linant, setting forth in its report the advantages that would result from their construction, and recommending a continuance of the work. The advantages were in a general way correctly stated, though exaggerated in much of the detail. The want of accurate knowledge of levels in the Public Works Department of Linant's time misled the Commission into stating that one of the advantages would be that the Khalig of Cairo could be made to flow throughout the year with a water surface at flood level! Still, notwithstanding the recommendations contained in the Report of the Commission, the Viceroy replied officially to the Minister, that the Commission was quite right, but he nevertheless did not want Barrages. The materials collected were therefore removed from the site of the projected regulators to other works, and the workshops dismantled for the sake of the wood of which they were constructed. And that was the end of M. Linant's Barrage, a child still-born.

A few years later, in 1842, Monsieur Mougel (afterwards Mougel Bey) arrived in Egypt to construct the graving dock in Alexandria. On an occasion presenting itself, he proposed to Mehemet Ali another system of carrying out the construction of the Barrages. He claimed to have discovered an artificial puzzuolana in Alexandria, which made the construction of a Barrage a more hopeful undertaking. His Highness approved the proposal and directed M. Mougel to prepare his project, at the same time calling upon M. Linant to give him all information possible, as well as the benefit of his experience. In compliance with this order M. Linant handed over his complete project to M. Mougel, not, we may be sure, without some feelings of bitterness as he parted with the unused baby clothes of his still-born child for another's child to wear.

In January 1843, M. Mougel laid his project before the Conseil des Ponts et Chaussées. The design of the Barrage, according to this project, gave thirty-nine arches to the Rosetta Barrage and forty-five to the Damietta, all of 8 metres width, divided by vertical iron uprights into two bays of 4 metres width. It was intended to hold up to 6 metres above Low Water Level. Mougel considered (and subsequent experience has shown him to have been right) that *all* the Low Nile water was required for irrigation; and that the work should be designed to provide for its being all utilized. But the Conseil des Ponts et Chaussées thought that this was "almost absolutely impossible" of attainment, as they calculated that the canals could not be made to carry the whole of the summer supply. And not only did they consider it to be impossible, but even undesirable, as navigation and sanitation along the two branches would suffer seriously, were the whole summer supply diverted into irrigation canals. Finally, the Council gave it as its opinion that the project had not been sufficiently studied.

But that was nothing to Mehemet Ali: sooner than delay, he adopted the project as it stood, and gave orders for the immediate construction of the Barrages under the direction of M. Mougel. The Barrage which now exists is the result of this order, but the original design was modified.

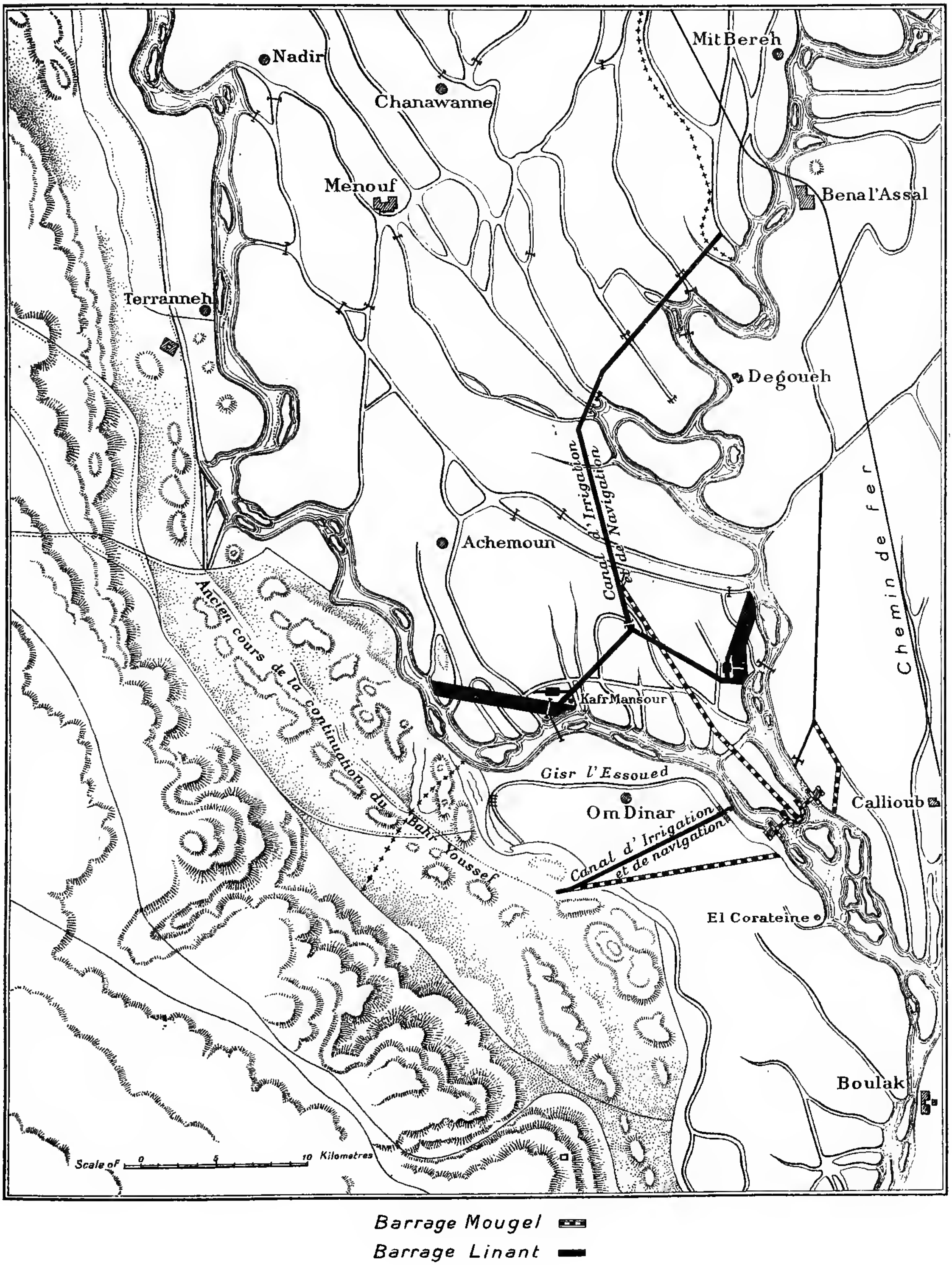
As Mehemet Ali's methods of setting on foot and executing great public works had a considerable effect on the manner of building the Barrage, and must therefore be held responsible, at least to some extent, for the resulting defects, an illustration of those methods is given in the following passage from Sir Charles Murray's "Memoir of Mohammed Ali," from which I have already quoted.

"The energy with which he pursued his ideas, and his puerile eagerness for their fulfilment were very Oriental. He required the genius of the ring and the genius of the lamp always at his command. There was one story illustrating these peculiarities that he used to relate himself with great glee.

"Stopping once upon his way from Cairo to Alexandria, and having determined upon making a canal, he sent for the chief engineer of the province. Having given him the length, breadth and depth of the canal required, he asked the engineer in what space of time he would undertake to make it. The man took out his pencil and paper, and having made his calculations, answered that, if the Pasha gave him an order on the governor of the district for the labour required, it might be finished in a year. The reply to this was a signal to the Pasha's servants to throw the engineer on his back and give him two hundred blows with a stick on the soles of his feet. This ceremony being concluded—'Here,' said the Pasha, 'is an order for the number of labourers you may require. I am going to Upper Egypt; I shall come back in four months. If the canal is not completed by the day of my return, you shall have three hundred more.' 'The work,' he would add with much self complacency,' was punctually executed.' "

It will be convenient before going further with this account to compare the two projects of M. Linant and M. Mougel. The sites chosen for M. Linant's Barrages were—on the Rosetta Branch 9 kilometres and on the Damietta 5 kilometres to the north of the present one (*see* Plate I), and the two separate Barrages on either branch of the river would have been 6 kilometres distant the one from the other. In the present Barrage, which is Mougel's, the two constructions are so near to each other as to almost form one work, so that it is the custom now to speak of the two together in the singular as "the Barrage." In consequence of this union, the regulation of the Barrages themselves, and of the Canal Heads taking off above them, is easily controlled by one Director in charge of the whole; and the daily examination of all the Regulators is much facilitated, especially now that a tramway for trollies connects all the parts of the Barrage by which the water distribution is effected. The separation of the Regulators by long distances, as in M. Linant's project, would not have been such a convenient arrangement as the one actually adopted. But M. Linant claims on behalf of his project, that he would have had more reliable constructions, since his works would have been built in good soil, while M. Mougel's were actually founded upon loose sand. Also, since the works, as designed by M. Linant, would have been built in the dry outside the course of the river (which would not have been diverted

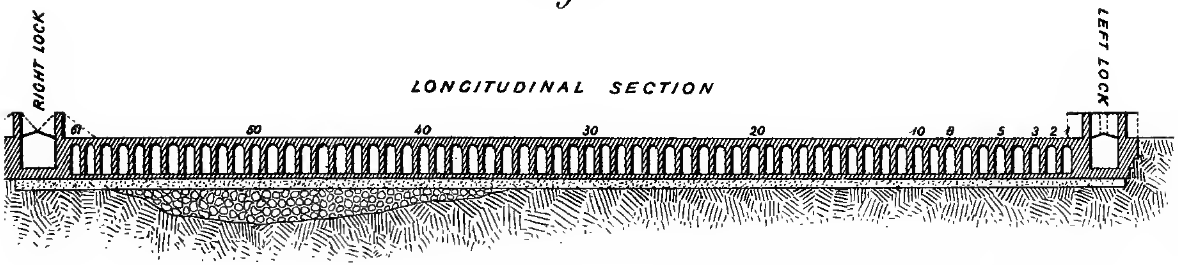
# PART OF LINANT'S MAP SHOWING ALTERNATIVE BARRAGE SITES



through them until they were complete), the foundations could have been given a level bed and the concrete have been laid in the dry: whereas, building as Mougel did, in the river bed itself, the work was founded on an uneven surface, and the concrete was, to a great extent, laid in running water. The varying levels of the bed are shown in Fig. 1, which is a longitudinal section along the Rosetta Barrage. At

ROSETTA BRANCH BARRAGE

*Fig. 1*



*From Willcocks "Egyptian Irrigation"*

the west end of this line the sand bed rose 4 metres above the summer low water level, while towards the east end the river bed was 16 metres below the same water level (*see* also Fig. 2). Hence the west end of the Barrage was founded on loose sand, and the east end on a mass of rubble stone, 12 metres in height and 60 metres broad at the deepest part, which was pitched in to form a platform for the concrete to be laid upon (*see* also Plate II.) The concrete layer was consequently formed in running water, and as it did not therefore set, it had to be relaid, probably more than once.

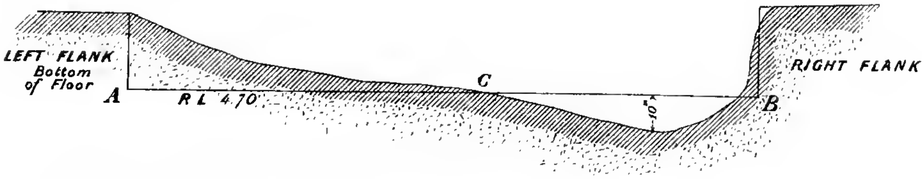
For the ten years succeeding the acceptance of M. Mougel's project in 1843, the construction of the Barrage was carried on fitfully with more or less rapidity and success. The Damietta Barrage was begun first, and no special difficulties are recorded as having been met with in connection with it. No account exists of the condition of the foundations, but Mougel stated that the work here is excellent, since it was practically built in the dry. Later examinations of the foundations by boring have confirmed this.

In June 1847 the Rosetta Barrage was begun. Mehemet Ali, impatient for the completion of the work, ordered that 1,000 cubic metres of concrete were to be laid daily, whether possible or not. It so happened that, in this year, the river level in April was more than one metre higher than it had been at the same time the year before. Difficulties were also occasioned in consequence of the earth excavated from the foundations having been thrown too near the edge of the pit, and therefore causing slips, which interfered with the work. M. Mougel attempted to carry out the Viceroy's order in spite of difficulties and technical objections to doing so, knowing that he would have been dismissed, had he acted otherwise. In went the concrete, as fast as it could be got in, to too shallow a depth at the west end, and into running water at the east end over the loose rubble mass. Naturally the lime of the concrete mixture was carried away by the current, and the concrete lost the ingredient which gave it the property of setting. Naturally also springs found their way through the material that remained and upon which the Barrage was to be founded.

The following account* of the manner in which the Barrage was constructed was given to Mr. Willcocks by Mougel Bey himself, and is therefore worth reproducing in full :—

" A level of 8·80 metres above the Mediterranean Sea (or 8·20 metres on the Barrage gauge ) was fixed as the mean bed of the river at the bifurcation. The floor was to be 3·50 metres deep, and consequently a reduced level of 4·70 metres was the formation level of the bottom of the floor. Owing to scour along the right bank of the Rosetta Branch, the bed of the river was some ten metres below this level at the deepest points ; while on the left bank there was considerable silt deposit above it.

*Fig. 2*



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* "*Egyptian Irrigation*" by Willcocks, 2nd edition, p. 263.

"The above Fig. 2 represents a cross-section of the Rosetta Branch at the site of the Barrage during construction, and the line AB the bottom of the floor; the part from A to C—where the floor is below the bed of the river—was first constructed. The sand was excavated as far as possible in the dry, and then two rows of sheet piling were driven along the up and downstream faces of the platform.

"In the cross-section Fig. 3, EF and GH are sheet piles; within the sheet piling the sand was dredged out down to a reduced level of 4·70 metres, and concrete skipped into the water to its full thickness of 3 metres, and then allowed to set. Next season the sand was removed from above the concrete KL, and a coffer-dam MN, Figs. 4 and 6, was erected on the concrete, enclosing the space to be occupied by about five openings. The coffer-dam was filled with stiff clay, made watertight and the water was pumped out. The springs through the concrete were then staunched, the stone and brickwork floor OP laid over the concrete, and the piers raised to one metre above water-level.

*Fig. 3*

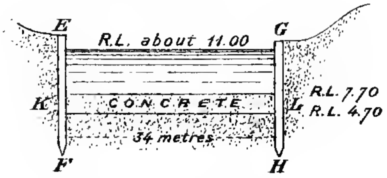
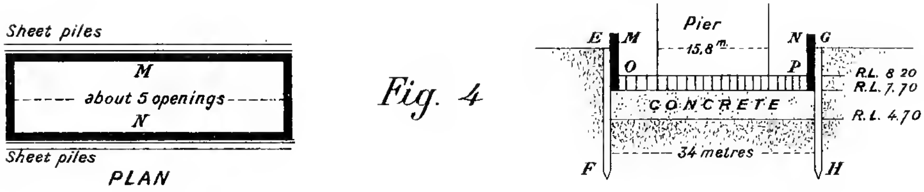


*Fig. 4*



"The coffer-dam was then moved forward, and the space to be occupied by five new openings enclosed, and treated in the same way. The sheet piling EF and GH was not cut down to floor level, but projected both up and downstream of the platform to a height of one metre above the floor. There seems to have been no difficulty experienced in this method of working, except under the arches numbered 7, 8, 9 and 10, near the left flank; here the sand was of a particularly fine quality, dark in colour and very light, with the springs strongly impregnated with decayed organic matter. In spite of the dredger working in still water, the fine sand poured in fast from between the piles, and after being dredged was allowed to accumulate to a height of eight metres and upwards, just outside the sheet piles. The more it accumulated the more the silt ran in, until the deepening of the trench became an impossibility. Mougel Bey wanted to postpone the work to the following year, but the Viceroy was urgent: men were crowded into the quicksand, the concrete skipped in, and the mixture of concrete and quicksand had to do duty for the floor. Mougel Bey says that the concrete there could not be more than 1·50 metres thick; Linant Pasha says that the springs here were always considerable, cracks appeared in the Barrages before any water was held up on the Barrage, and eventually this part of the Barrage failed and was surrounded by by a coffer-dam (Fig. 5).

*Fig. 5*

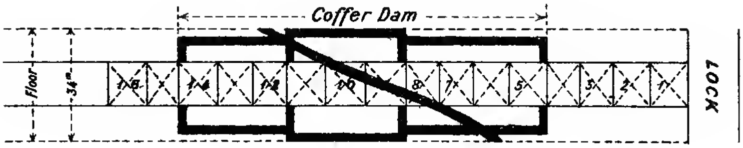
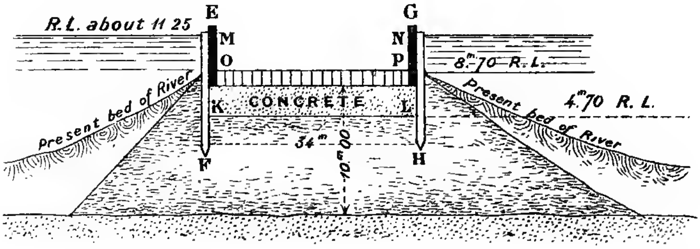


*Fig. 6*



"Referring to the cross-section of the river (Fig. 2), it will be seen that the construction of the Barrage along the part CB, where the floor lies higher than the bed of the river, could not have been carried out as above. Here a mass of loose stone was pitched into the river from boats, until the upper surface of the tipped stone corresponded with the bottom of the platform, or the line AB. Into this barrier of stone, sheet piling (along the up and downstream edges of the platform) was driven in as far as it could go. Sail cloth was laid on the upstream side of the piles and held against the piles by the force of the current. The concrete was skipped into the water between the piles. Theoretically the tipped stone was at R.L. 4·70, but practically it must have been much lower, to allow of the extra concrete being skipped in here. As much of this concrete was skipped into running water, great part of the lime was washed away, according to Linant Pasha. Subsequently when the coffer-dam was erected on the concrete for the completion of the floor and superstructure, the springs in places were so excessive that the floor level had to be raised fifty centimetres above the general level. The concrete was composed of broken stone, pure lime and artificial puzzuolana in the ordinary proportions. No exact record exists of the proportions, as far as I have been able to ascertain. Much of this concrete has not set, and in places has been found like pudding, though in others it is as hard as rock."

Meantime, while this work was going on, Mehemet Ali died in 1848 without seeing the completion of the Barrage, which was to be many years before it recovered the injury done to its constitution by his impatience and impetuosity. He was succeeded by Abbas Pasha, who, in March 1852, having no faith in the success of the Barrage as being constructed, was desirous of abandoning the work; but he did not do so for fear of public opinion. At this same time also M. Linant declared himself in favour of pumping establishments in preference to completing the Barrage, and defended his change of opinion on the ground that during the last ten years pumping machinery had been much improved and rendered economical.

In April 1853, Abbas Pasha, not being satisfied with the progress made, dismissed M. Mougel, and ordered him to hand over the incomplete Barrage to Mazhar Bey. At the time of transfer a Commission reported on it to the effect that the concrete floor over the rubble heap and elsewhere was in a bad state and that springs found their way through it. M. Linant relates that at the time of transfer the work was far from being finished, as there were scarcely any of the piers constructed to above water-level; he also adds that up to this time forty-seven million francs had been spent on the work, besides the labour of the Corvée and soldiers. The state of the work in 1853, according to M. Linant, is shown on Plate II.

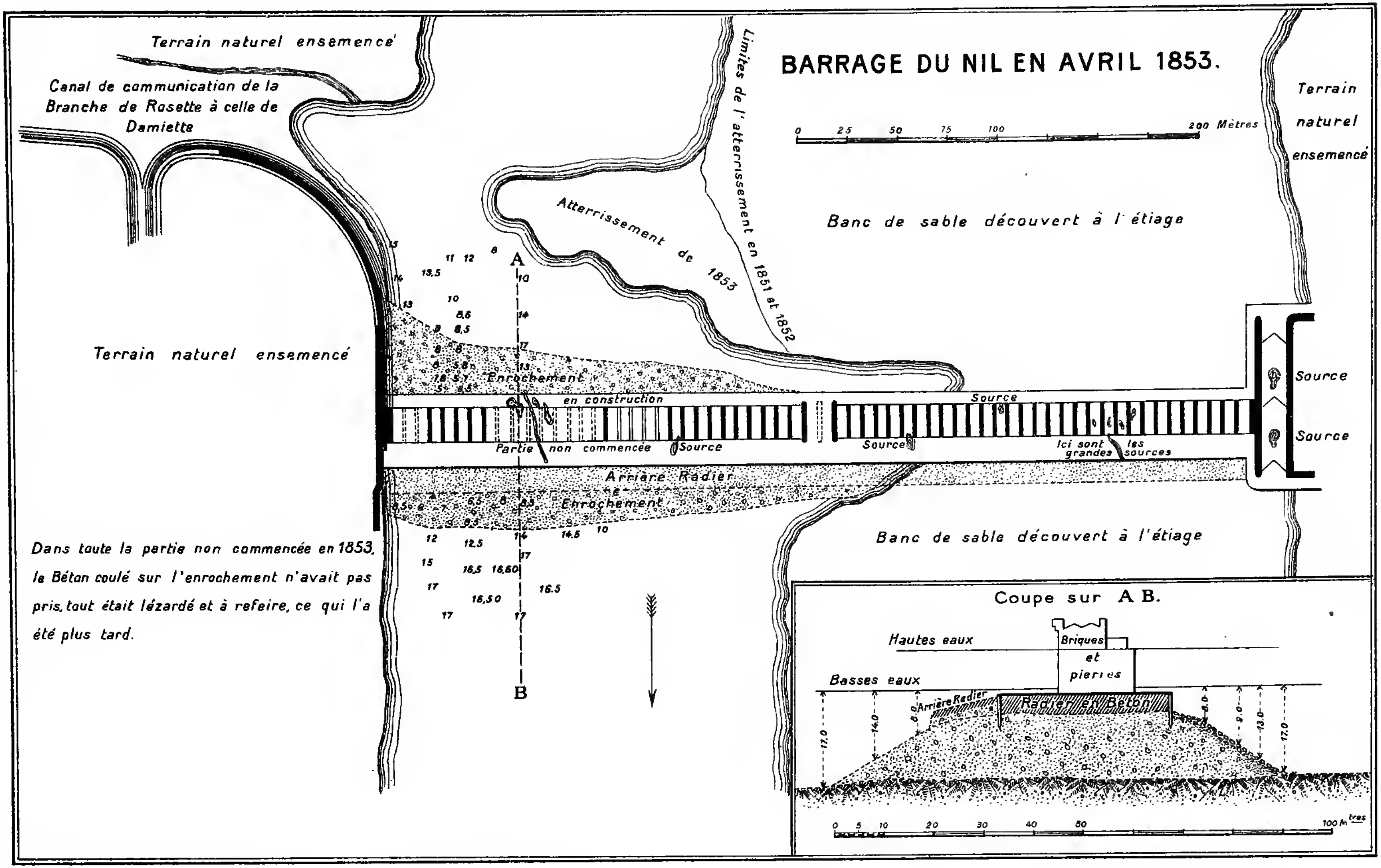
In spite of the Report made at the time of transfer, work was continued without remedying the defects in the foundations and without making the concrete layer sound; the piers were completed and the whole superstructure of road, pathways, parapets and turrets completed by 1861. The cost, exclusive of the value of the Corvée labour, is said to have been £1,880,000.

And now we pass from the period of construction to the period of Commissions and Reports.

When Said Pasha succeeded Abbas Pasha in 1853, Mougel returned to Egypt and was re-employed in the Public Works Ministry, though he did not take charge of the Barrage Works again. And so, in December 1855, we still find Mougel in office when the Commission of savants, who had come to Egypt to study the Suez Canal Project, was consulted by the Viceroy concerning several matters, of which the Barrage was the most important. The condition of the Barrage at this time was not clearly set forth in the Commission's Proceedings, but it is stated that there remained to be executed one-third of the floor, 400 metres of the apron, and six arches of the Damietta Barrage as well as the closing apparatus. The object of the Barrage was stated to be the raising of the water-level in summer by 4½ metres.

Said Pasha's hobby was soldiering in time of peace, and it occurred to him that the Barrage and its surroundings at the Head of the Delta was a unique position for a military fort and centre. He imagined that, by means of the Barrage and its canals, he could raise the water high enough to inundate the whole Delta from its head to the sea-coast, and so obliterate all the land routes, and even endanger the existence of an army which might have disembarked and have advanced inland. Further, he thought that, if a fleet made its way up the Nile, he would make short work of it by means of his Barrages and fortifications connected with them. Thus would he deal with an enemy invading the country from the coast. Should an enemy come by land from the east or west or south, avoiding the Delta, he

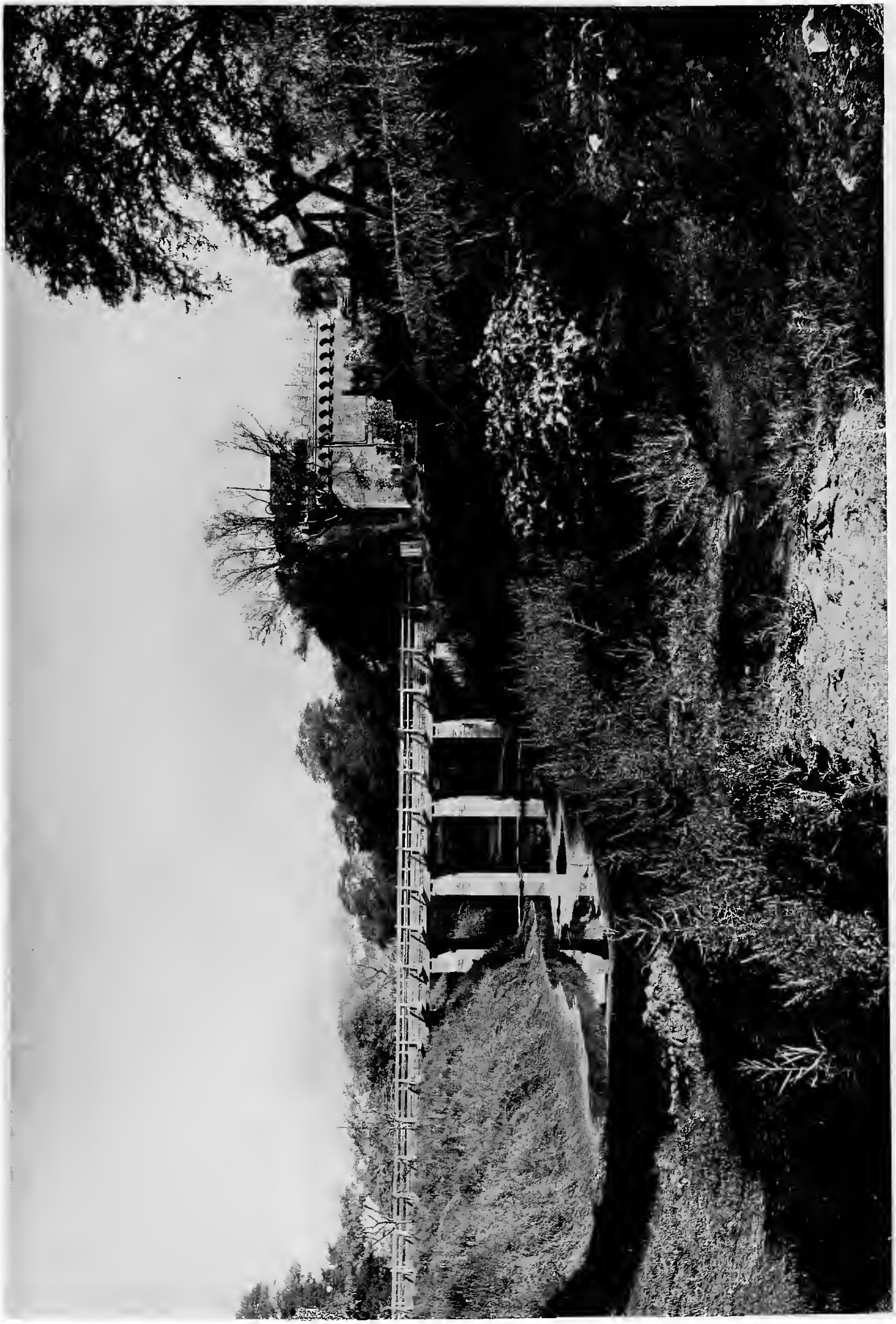
# BARRAGE DU NIL EN AVRIL 1853.


Terrain naturel ensemencé
Canal de communication de la Branche de Rosette à celle de Damiette
Terrain naturel ensemencé
Limites de l'atterrissement en 1851 et 1852
Atterrissement de 1853
0 25 50 75 100 200 Mètres
Banc de sable découvert à l'étiage
Terrain naturel ensemencé
Source
Source
Source
Source
Ici sont les grandes sources
Source
Enrochement
en construction
Partie non commencée
Arrière Radier
Enrochement
Banc de sable découvert à l'étiage
A
B
15
11 12
8
13,5
10
14
10
13
8,6
14
8,5
17
13
12
12,5
14
14,5
10
17
15
16,5
16,60
16,5
17
16,50
17
17
Coupe sur A B.
Hautes eaux
Basses eaux
Briques
et
pierres
Arrière Radier
Radier en Béton
17.0
14.0
8.0
8.0
9.0
13.0
17.0
0 5 10 20 30 40 50 100 Mètres

Dans toute la partie non commencée en 1853, le Béton coulé sur l'enrochement n'avait pas pris, tout était lézardé et à refaire, ce qui l'a été plus tard.

PLATE III.

BRIDGE OVER FORT DITCH.
(Photograph by the Author.)



reckoned that, with his strongly fortified "têtes de ponts" at either end of the Barrage, he would be strong enough to maintain himself in his citadel, "Kilat-Saidieh," against any army.

So one of the questions put to the Commission of 1855 was concerning the width of the central canal at the point where it passed through the fortifications. The military engineers demanded that the width should not exceed 15 metres. In the record of the Proceedings it is stated that the Commission think the defence should adapt itself to the irrigation, the latter being essential to the country. Nevertheless, in spite of this sensible view, the recommendations of the Commission agreed with the demand of the military engineers, and the members approved of the throttling of the central Delta.

The fortifications were commenced in 1856, the first stone having been laid on the 12th March with solemn ceremony. The diplomatic corps and the Duke and Duchess of Brabant were present. Linant Pasha remarks that the "mauvais temps" of the day was bad for the smart uniforms. Probably the first stone was laid in the opening dust-storm of the Khamsin season.

The fortifications were all designed on the now obsolete Vauban system with bastions, sally-ports, casemates, counterscarp galleries, draw-bridges, machicoulis galleries, etc., familiar to all Woolwich cadets of the time of H. R. H. the Duke of Connaught. They are naturally of no military use now, but they add to the picturesqueness of different points of the Barrage grounds, and are interesting as specimens of an obsolete system. A view of the bridge over the old fort ditch, leading to one of the old gateways, is given on Plate III.

The condition of the Barrage, after it was supposed to be finished in 1861, is recorded in the Reports of two more Commissions, one appointed on the 13th November 1861, and the other on the 4th July 1863. At the time of the first of these two Commissions, no other cracks were remarked except those which existed from the beginning of the construction in the 1st, 2nd and 3rd arches of the west end of the Rosetta Barrage, and these did not appear dangerous. The Commission considered that little remained to be done to complete the Barrage and fit it for the object for which it was designed; but recommended that, before holding up the water at all, the floor should be finished and the springs should be stopped by the aid of a diving-boat ("bateau-plongeur") in preference to the employment of dams ("batardeau"); for it was feared that if a head were put on the work, water would pass through the loose rubble heap. The first Commission after making this proposal, adjourned for more information, which it never got.

The second Commission of July 1863 pointed out that the works recommended by the former Commission had not been carried out, that the experiments required had not been made and that the springs had not been stopped. The system of gates was condemned. This Commission came to much the same conclusions as the former, and recommended postponing the digging of the main canals taking off above the Barrage, until it had been tested.

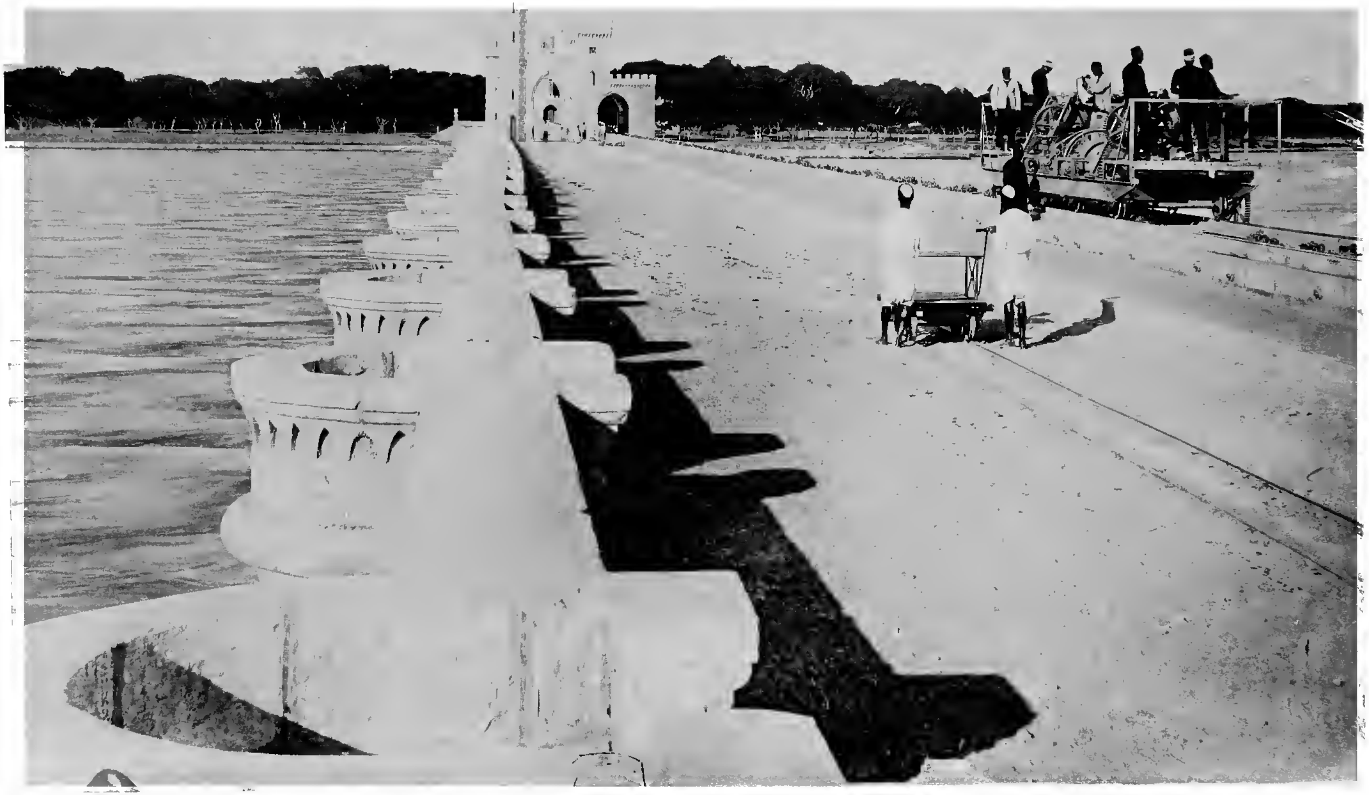
But in this year the want of water in the Damietta Branch made itself felt during the summer, and, in order to feed the summer canals' the gates of the Rosetta Branch, which had been erected, were closed, and the water-level raised above the Barrage from 1·00 metre to 1·40 metre. The result was that the sand below the floor was forced out by the pressure, and ominous cracks appeared. Later, in 1867, a section of the Rosetta Barrage, consisting of ten openings (Nos. 5 to 14) towards the west end, separated from the rest of the work and moved perceptibly downstream. (This was visible up to 1897 in the existing work, and is clearly shown by the shadow of the parapet wall in Plate IV. The parapet has been, since, dismantled and rebuilt.) These ten openings were then enclosed within a coffer-dam five metres high and two metres wide, composed of a wooden framework, filled with stiff clay, overlaid by stone resting on the platform.

Linant Pasha's last connection with the Barrages (which in principle he claims to have proposed, though the actual project adopted was M. Mougel's and not his) appears to have been the writing of a Report on it in 1871. This is his account of the work as it existed then:

"Le Barrage est comme un corps gangrené: il est recouvert d'un beau surtout, mais la maladie le travaille intérieurement; toutes ces sources sont autant de fistules, qui, quand on veut les fermer, circulent intérieurement et se reproduisent plus loin. Il faut de grandes opérations, de grands remèdes et non des palliatifs, qui ne feraient qu'empirer le mal."

In this same Report Linant Pasha admitted the possibility of putting the Barrage in order, but the uncertainty and the expense

PLATE IV.



VIEW OF ROADWAY OVER ROSETTA BARRAGE, SHOWING DISPLACEMENT OF PARAPET WALL.

(Photograph by Mr. Allan F. Joseph.)

frightened him. He would not throw good money after bad. He estimated that the sum required to do what was necessary would be twenty-five million francs, which he remarked was far from being exaggerated, and he calculated that it would take five years to do the work. And then he proceeded to make calculations to show that it was preferable to set up steam pumps. This estimate of Linant's should be remembered, when what has been done since and the cost of doing it is read about further on.

In April of the same year, 1871, that Linant Pasha wrote his note for the Khedive, Messieurs Lavalley and de Langaudin made a joint report, recommending an expenditure of £20,000 in repairs to the floors of arches 6 to 13 of the Rosetta Barrage, the repairs to consist of a layer of concrete three metres thick laid over the defective floors. This done, the Barrage was to be tested by closing the arches and finding out what head it would stand.

These recommendations were unfavourably criticised in similar terms by both Aly Pasha Moubarak, Minister of Public Instruction and Wakfs, and Bahgat Pasha, Minister of Public Works. The criticisms were accompanied by suggestions more vague and less practical than the proposals under consideration. The two Pashas probably got their heads very close together when they wrote their separate notes, which, however, contain nothing worthy of immortality.

Still one more short report was written in 1871 by Mr. D. K. Clark (engineer representing Mr. J. Fowler). This note contains a well-deserved condemnation of the form of gate adopted and under trial in some of the arches of the Barrage at the time it was written.

The next to be called in consultation to prescribe for the despaired of patient was a well-known English engineer, the late Sir John (then Mr.) Fowler. He examined the Barrage in 1876, pronounced the piers and arches, so far as visible, to be of good construction, but the floor to be defective. The floor-surface of brick and stone was not in a bad state, but the concrete below was, in some places being no more than a confused mass of small stones or gravel. He was convinced that the foundations of the floor were too shallow, and that considerable and expensive works were required to put the Barrage into working order, half measures being useless.

Sir John Fowler proposed not to abandon the Barrage entirely, but to utilise the existing work as far as possible, and to obtain the additional height, to which it was desired to raise the water-level, by means of a new and independent construction. He recommended that the gates of the existing Barrage be completed and be made efficient, that a new line of gates be constructed on foundations carried to a great depth immediately downstream of the existing floor, and that the river bed beyond it be protected against scour.

He pointed out that, had not the floor been cracked, the sand of the foundations might have been confined between up and downstream curtain walls, and the Barrage have been made to hold up the full four and a half metres desired. But as the floor and foundations were cracked, the sand would have found its way out between the cracks under the pressure of the water, and the foundations have been undermined.

As the Barrage had actually supported a head of 1·50 metres, Sir John proposed to utilise it in future to this extent. The remaining 3 metres was to be held up by gates fixed on a massive wall 8 metres thick and 18 metres deep below Low Water Level. The river bed immediately downstream of this wall was to be covered by a wide layer of rubble intersected by two rows of heavy concrete blocks 8 metres below Low Water Level, so as to obtain a water-cushion of a sufficient depth to deaden the fall of the water. One row was to be up against the curtain wall and the other at a distance of 24 metres from it. Between these rows and beyond the second row was to be a protective layer of loose rubble pitching. The cross-section, Plate V, shows clearly the form of curtain wall proposed.

But the deep wall had to be made without endangering the stability of the existing structure. Sir John proposed to make it in sections of 35-metre lengths by the aid of iron caissons and compressed air, and to unite the different sections by means of end grooves, by which a tight joint could be obtained in an ingenious way, not very easy to describe. On the top of this curtain wall were to be strongly bolted the iron uprights, which were to hold the downstream row of gates.

The cost of carrying these proposals out, including repairs to the locks, was estimated at £1,000,000 allowing for probable contingencies; or at £1,200,000 allowing for all reasonably possible contingencies. Sir John Fowler considered that the work could be easily completed in three years, if carried out with energy and without interruption.

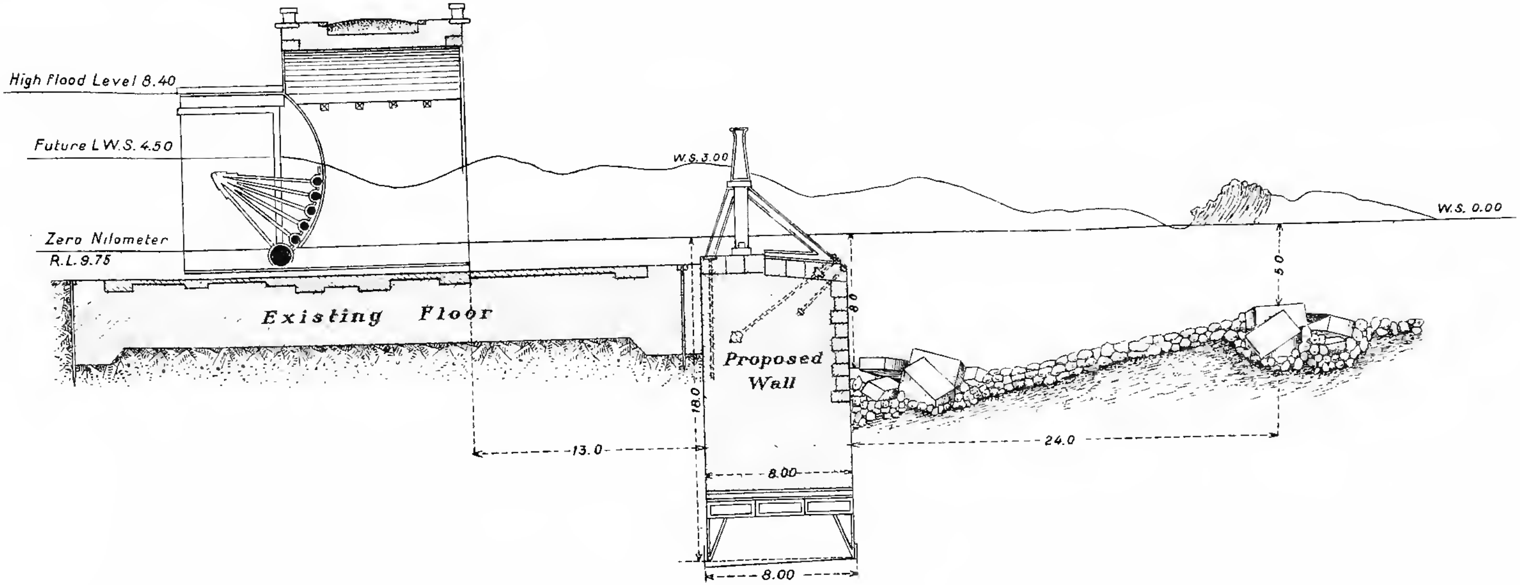
But the Khedive, Ismail Pasha, who was a prodigy of a spendthrift

PLATE V

# CROSS SECTION OF THE BARRAGE

Showing the work proposed by Sir John Fowler

1876.



in the gratification of his extravagant whims, refused to sanction this outlay on a work that was all-important to the country, probably because faith in the success of the work was dead.

In his Report Sir J. Fowler also, like Linant Pasha in 1871, discusses the relative cost of providing for irrigation by the restoration of the Barrage on the one hand and by the establishment of large pumping stations on the other; but, unlike Linant's, his figures prove that the pump project would be not only more costly but less efficient.

At, or about, the same time that Sir John Fowler was called upon to report on the Barrage, Mr. Gatget, a distinguisheed engineer representing the Fives Lille Company, was also invited by the Viceroy to do the same. He too recommended the construction of a deep wall close to and separate from the Barrage, but *above* the existing work at a distance of 40 metres from it. This wall was to be carried down to a depth of 22 metres below zero (zero was probably L.W. L.), and on it were to be built sluices to hold up 5·80 metres of water. The space between the old and new works was to be filled up by extending the existing floor.

But not satiated yet with Reports of Commissions, and Reports and Joint Reports of distinguished engineers, the Khedive must have reports upon Reports; and so, having his opportunity, he invited Sir Charles Hartley, K.C.M.G., to report on the projects of Sir J. Fowler and Mr. Gatget, the year after they were made. After visiting the Barrage with Mr. Gatget and Ali Pasha Moubarak, the then Minister of Public Works, Sir Charles gave his opinion as follows :—

"After a close study of the subject in all its bearings, I agree with Mr. Fowler and Mr. Gatget in their opinion. Firstly, that it is more desirable to utilise the Barrage with its bridges, locks, canals, etc., than to resort to other proposed solutions, such as the more costly expedients of establishing a "grand canal de dérivation" high up the Nile to bring its waters at the low water season to the required level at the head of the Delta; of constructing an entirely new barrage at some point between Cairo and the existing work, or of gaining the same end by means of pumping only; and, secondly, that the failure of the Barrage is due to defective foundations and not to any violation of general principles in the original design."

There was yet another distinguished engineer who reported on the Barrage in the same year that Sir J. Fowler and Mr. Gatget made their Reports, namely Lieut. Gen. F. H. Rundall, R.E., a well-known Anglo-Indian Irrigation engineer, formerly Inspector General of Irrigation to the Government of India. His Report is dated 17th May 1876, and was written for the information of H.H. the Khedive. The manner of restoring the Barrage, as recommended by General Rundall, is very nearly that which was actually adopted; and further, the cost of the restoration was correctly estimated.

Discussing the condition of the floor, he gives his opinion as follows:—

"I cannot, however, but think myself that the great mass of the substructure must still be in a sound condition, otherwise the great superincumbent weight, which it has to support, must have caused a much more serious settlement than even that which has taken place in the left flank of the Rosetta portion."

"My own opinion is that the original foundations of the Barrage were ample as regards *depth*, provided that they had been faithfully built; but that they were deficient as regards *breadth* and the protection given both on the upper and lower sides of the flooring."

He recommended obtaining breadth principally by extending the flooring and protective rubble aprons, not with the object of preventing springs finding their way below the work, but as a precaution against scour from the rush of water over the floor. General Rundall also does not class the Barrage with the incurables, for he remarks:

"The conclusion at which I have arrived is that the present Barrage may yet be made perfectly capable of fulfilling the purpose of its original construction."

He based the following recommendations on the understanding that two essential conditions be fulfilled, viz.—that the flooring be laid dry for a thorough examination and previous to its thorough repair: and that the necessary works be undertaken first to restore and afterwards to maintain a proper equilibrium of the river flood.

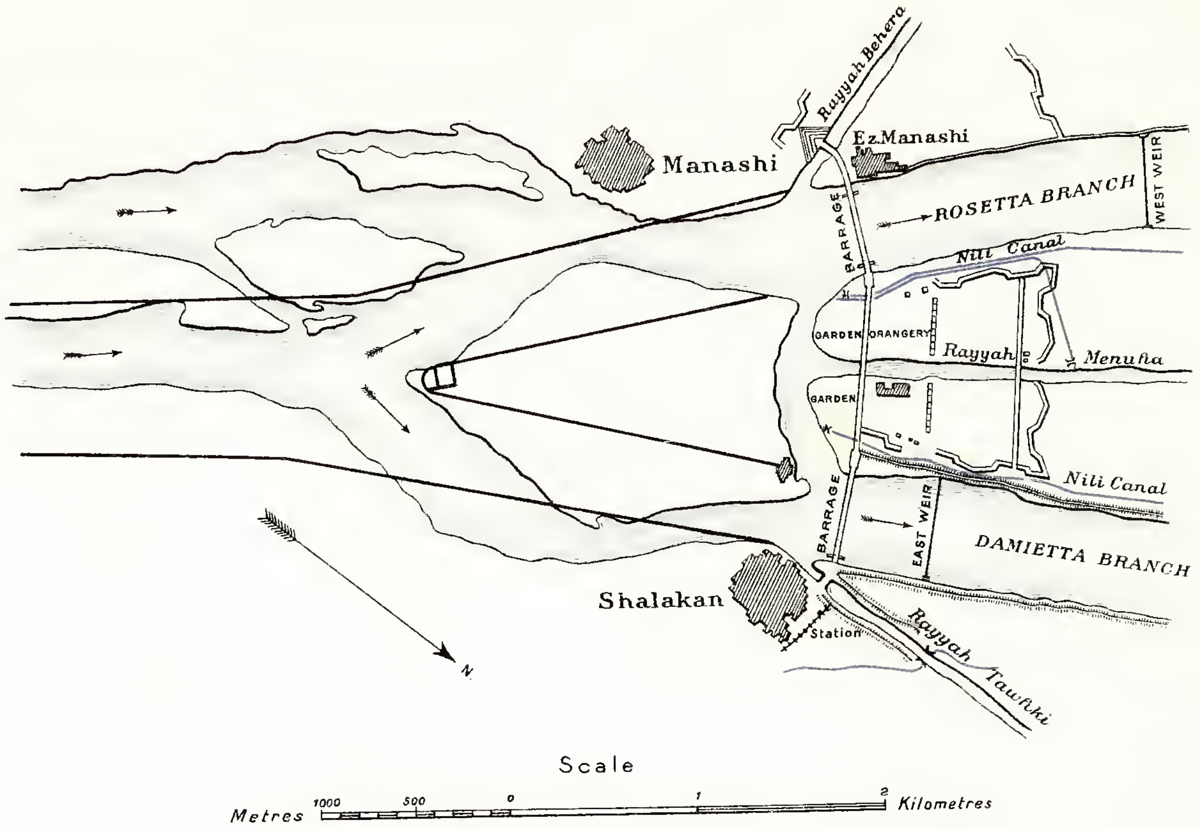
The works he considered then necessary were:—

1. Repairs of the floor with strong cement masonry, raising its level one metre and covering it with dressed Ashlar blocks.

2. Extension of floor upstream by an apron 25 metres wide and 3 metres thick, and, in addition, the formation of a curtain wall of

PLATE VI.

# RIVER AND CANALS AT THE BARRAGE.



masonry wells sunk 8 metres, or to the depth of the existing rough stone.

3. Extension of the floor downstream by an apron 60 metres wide and 3 metres thick with two curtain walls like the upstream one.

4. Substitution of needle system of closure for the then existing gates.

He estimated that the repair work would cost £400,000, with £100,000 added for training the river and changing the gates—in all £500,000.

If the list of works recommended in this Report and their estimated cost is compared with the account of work done and expenditure incurred in the actual operations of restoring the Barrage, it will be seen what a close agreement there is between the two. In the work, as carried out, the curtain walls have been omitted, and the needle system of closure has not been adopted, but the rest of the recommendations have been in principle carried out.

Read by the light of the experience and knowledge gained since 1875, General Rundall's Report is recognised as being that of an expert, who had sound views of the situation and had formed a correct estimate of the condition of the Barrages.

In his Report Generall Rundall lays great stress on the necessity of training the river up-stream of the Barrage, so that its currents shall set in proper directions on the two sections of it, and the river discharge be divided in correct proportions between the two branches. This training work was commenced in 1884, and has been continued ever since at an average yearly expenditure of about £E.3,000. The operations have been successful in diverting the main river from the western to the central channel; and, if they are persevered with, complete success will attend the policy of gentle persuasion that is being followed, and, in due time, the river will form and flow in the channels shown by the thick lines on the accompanying plan (Plate VI) as those which it is desired that it shall adopt.

As a final result of all these Commissions and Reports and in spite of some of them, Rousseau Pasha, Director General of Publics Works, in his yearly Report of 1883 on Irrigation, pronounced that the Barrage in its existing state could only be used as a distributor of the river discharge between the two branches. To make it fit to serve even this purpose only, he proposed to spend £400,000 in raising the floor of the Rosetta Barrage, so as to enable it, with the addition of suitable gates, to hold up a head not exceeding two metres; and to leave the Damietta Barrage alone, merely maintaining it as a bridge for traffic. The irrigation of Lower Egypt he proposed to provide for by a system of pumping stations.

Having made up his mind in favour of pumps, Rousseau Pasha stated the objections against the Barrage project. The first objection was that the cost of restoring or repairing it would be such as to be prohibitive. The restoration of both Barrages has since been carried out successfully at a total cost of £E.465,000,—not a prohibitive cost; so this objection has been answered.

The second objection was that he considered that the utilisation of the Barrage would affect the régime of the Nile inconveniently, and cause immense deposits up-stream of it. This objection has also been answered by experience showing that what Rousseau Pasha feared does not take place.

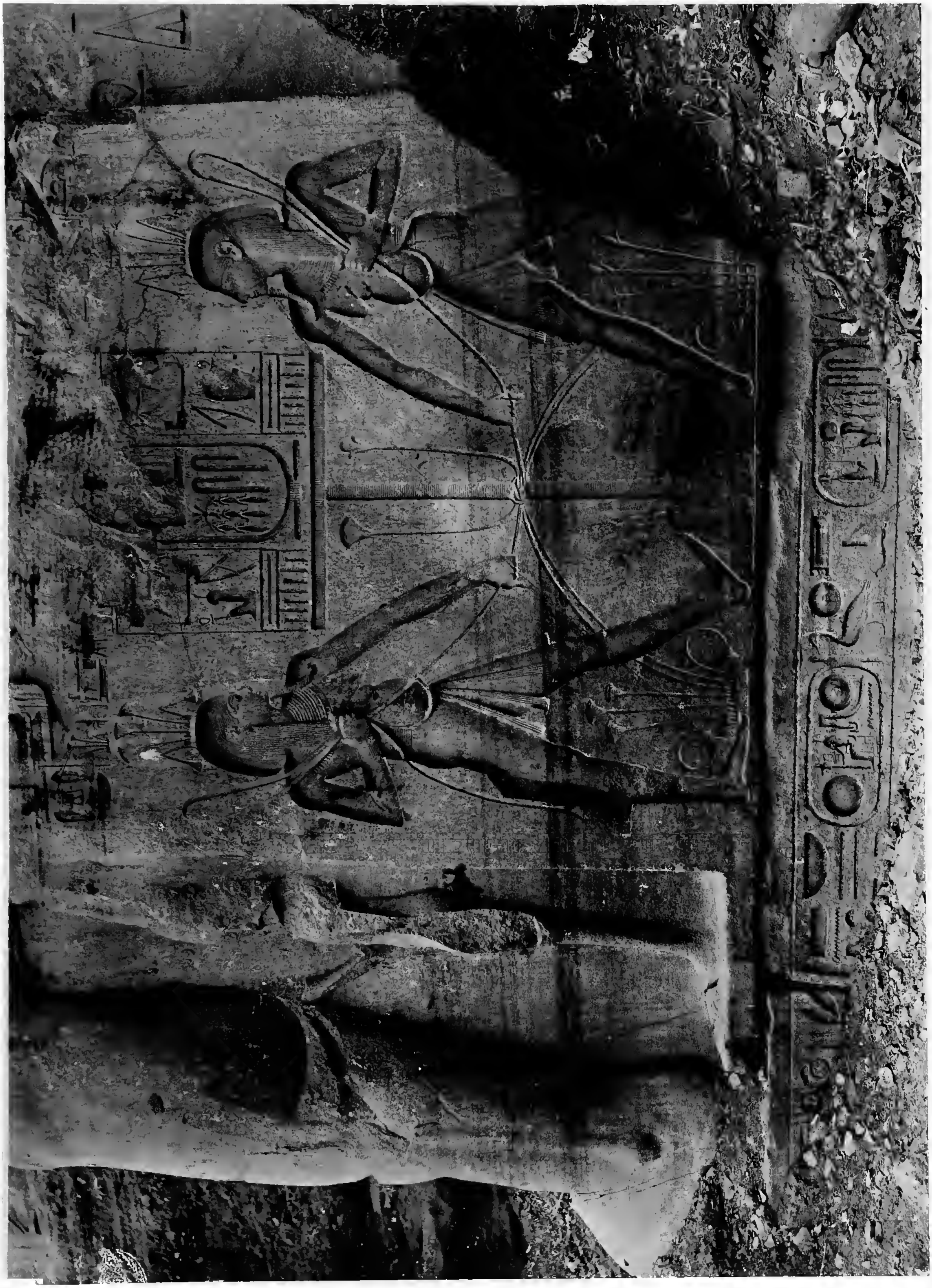
The third objection was that it would not only be necessary to restore the Barrage, but to remodel the whole canal system at great expense. This remodelling has since been carried out at a moderate expenditure.

The fourth objection was that the country would be dependent on one work. This is only an objection when the work can *not* be depended on.

The fifth and last objection was that the high level, at which the water would be maintained, would cause damage to land from infiltration. This objection experience has shown to be a real one, but it applies with far greater force to the system of irrigation by pumping, as it was claimed in support of this system that it would deliver water on to the surface of the land without any further lifting on the part of the cultivator.

But as experience and accomplished facts had not disposed of these objections in 1883, the Barrage stood condemned in an official document to play a minor part in the irrigation of Lower Egypt to that for which it was originally designed, and it was accounted of no reputation.

PLATE VII.



BINDING THE LANDS OF THE NILE.

(Photograph by the Author.)

# CHAPTER II.

## DESCRIPTION OF THE BARRAGE AND ITS OBJECT.

THE object of the Barrage is to obtain control over the Nile at the Head of the Delta, a control absolute in summer and partial in a low flood, but non-existent or rather not asserted in a full flood.

On the pedestals of many of the royal statues of ancient Egypt is to be found a device which symbolises the king's authority over the united kingdom of Upper and Lower Egypt. A scene in the coronation ceremonies of the Pharaoh gave public expression to the idea of union, and was the origin of the record of it which exists in the device. The particular example reproduced as Plate VII is to be found on the pedestal of the statue of Ramses II which stands on the west flank of the entrance leading to the Luxor temple through the main pylon. Professor Maspero has interpreted to me the meaning of the design. Its general signification is that of the union of the two lands under the control of a single ruler, and it is called the binding of the two lands. The central vertical shaft—like a spade with its crosshandle—about which the binding takes place, and above which is the King's cartouche, is the symbol of Union and Control. The two figures represent the Gods of the Upper and Lower Niles binding together the lands of the lotus and papyrus into one united Kingdom under the Pharaoh. The richness of the country over which the Nile gods preside is indicated by the overfed appearance of their bodies. The symbolism of this device of more than four thousand years ago might appropriately be applied to the modern works at the head of the Delta where the Nile bifurcates. The well favoured gods may be taken to personify the Barrages astride of either branch of the river, the one branch being represented by the lotus group between the feet of the right hand god, and the other by the papyrus of the god on the left hand. By the power of these two the river is bound and brought under the control of the Government represented by the King's cartouche above.

There is another device of ancient Egypt, interesting in this connection, which depicts what was the early conception of the source of the Nile. It is to be found in Hadrian's Portal on the West of the Temple of Isis on the island of Philæ. The goddess of the Nile, portrayed as a female figure with a head-tire of papyrus reeds, kneels in a cave with the sacred serpent surrounding her, and pours out the water of the river from two vases held in either hand. Above, perched on the granite boulders, a vulture (Muth) and a hawk (Horus) do sentry duty. Leave out the granite boulders and the birds, and the device would be a fit symbol of the Nile at the Barrage, where the twin branches of the river have their origin. For this reason it was chosen for the cover of this book.

The two branches divide the Delta into three separate divisions; the Barrage consists of Regulators built across each branch of the Nile at the apex of the Delta, and the irrigation of the three divisions is provided for by three main canals fed from the high-level water above the Barrage (*see* Plate VI.) The west division is the Province of Beherah and is irrigated by the Rayyah Beherah; the central division comprises the Menufiyah and Gharbiyah Provinces and is irrigated by the Rayyah Menufiyah; and the east division, comprising the Provinces of Kaliubiyah, Sharkiyah and Dakahliyah is irrigated by the Rayyah Tewfiki (made in 1889), assisted by the canals Ismailiyah, Sharkawiyah and Basusiyah. These last three canals take off from the right bank of the Nile between Cairo and the Barrage, and are also affected by the regulation of the river level at the Barrage: they provide irrigation for the Province of Kaliubiyah and the greater part of Sharkiyah.

The Rosetta Barrage has sixty-one arches and two locks, and is 465 metres long between the flanks: the Damietta Barrage had originally seventy-one arches (since reduced to sixty-one) and two locks, and was 535 metres long.

The Barrages, according to the originally accepted design, had respectively seventy-two and sixty-two arches, and also a navigable opening in the centre of each Barrage, 14·50 metres in width, which it was intended to leave always open. These navigable openings were converted into two arches, each of 5·50 metres span, and the place of three end arches was occupied by a lock constructed on the flank where no lock had been provided in the original design. The two Barrages are separated by a revetment wall about 1,000 metres in length, in the middle of which is situated the head of the Rayyah Menufiyah. The arches of the Barrages are all of 5 metres span, except the two in the centre, which are 5·50 metres. They are fitted with gates which are used to close the openings during summer with the object of raising the water-level, but which are lifted clear of the water in flood to allow a free passage for the river. It was originally intended that the Barrage should be capable of raising the water-level, when the river was at its lowest, by 4½ metres or 14 feet 9 inches, but this it was never equal to doing.

A peculiar feature of the Barrage, before its restoration, was an iron grating, 30 centimetres high, fixed into the piers across each opening between the bottom of the gates and the floor surface. These gratings allowed of a free passage of water when the gates were down. They were originally put in to prevent deposit of mud in front of the gates when shut. The gratings on the Rosetta Barrage were capable of discharging, with a head of 1·75 metres, over 240 cubic metres a second, according to Mr. Willcocks. It was found that the severe action below the Barrage, when a gate was lowered to its full extent, was due to these iron gratings, and not, as it had been supposed, to a honey-combed foundation. Mr. Willcocks remarked in the first edition of "Egyptian Irrigation," that this fact was apparently unknown to the writers of the reports on the Barrages, and pointed out that it ought to have been evident that, if all the action observed was due to fissures in the foundation, the Barrage would have been swept away many years before. But, though the existence of these iron gratings seems to have been forgotten in 1884, it was not so in 1871; for M. Lavalley, in a Report on the Barrage dated 10th April 1871, refers to them in the following passage:—

"Enfin les ouvertures qui existent dans les seuils en fonte devront être bouchées. Les pertes d'eau qui se feraient par ces seuils sont telles, qu'elles ne permettraient même pas d'atteindre à l'étiage une charge d'eau d'un mètre. La dénivellation de 1·75 mètre qui a été constatée était due sans doute à la hauteur du Nil à ce moment et à ce qu'un certain nombre d'ouvertures étaient déja obstruées."

Another peculiarity was the original form of iron gate with which some of the openings had been fitted. The gates were formed of a succession of hollow cylinders of varying diameter united by doublewalled diaphragms so as to form a species of caisson. They were 5 metres broad and 5½ metres high, shaped as the arc of a circle, and supported at either end by iron rods radiating from the centre to the arc ; these rods were attached at the centres of the arcs to massive iron collars working round wrought-iron pivots fixed in cast-iron blocks embedded in the masonry of the piers. They were designed to close or open themselves automatically, according as they were filled by water or compressed air, so as to constantly maintain the normal head of 4½ metres. The compressed air was to be supplied by a pump set in motion by the current of the river, so regulated by a valve and float that the air should escape freely if the level were exceeded. Thus it was fondly hoped that the only manipulation of the gates that would be necessary would be the raising them out of water once a year on the arrival of the flood.

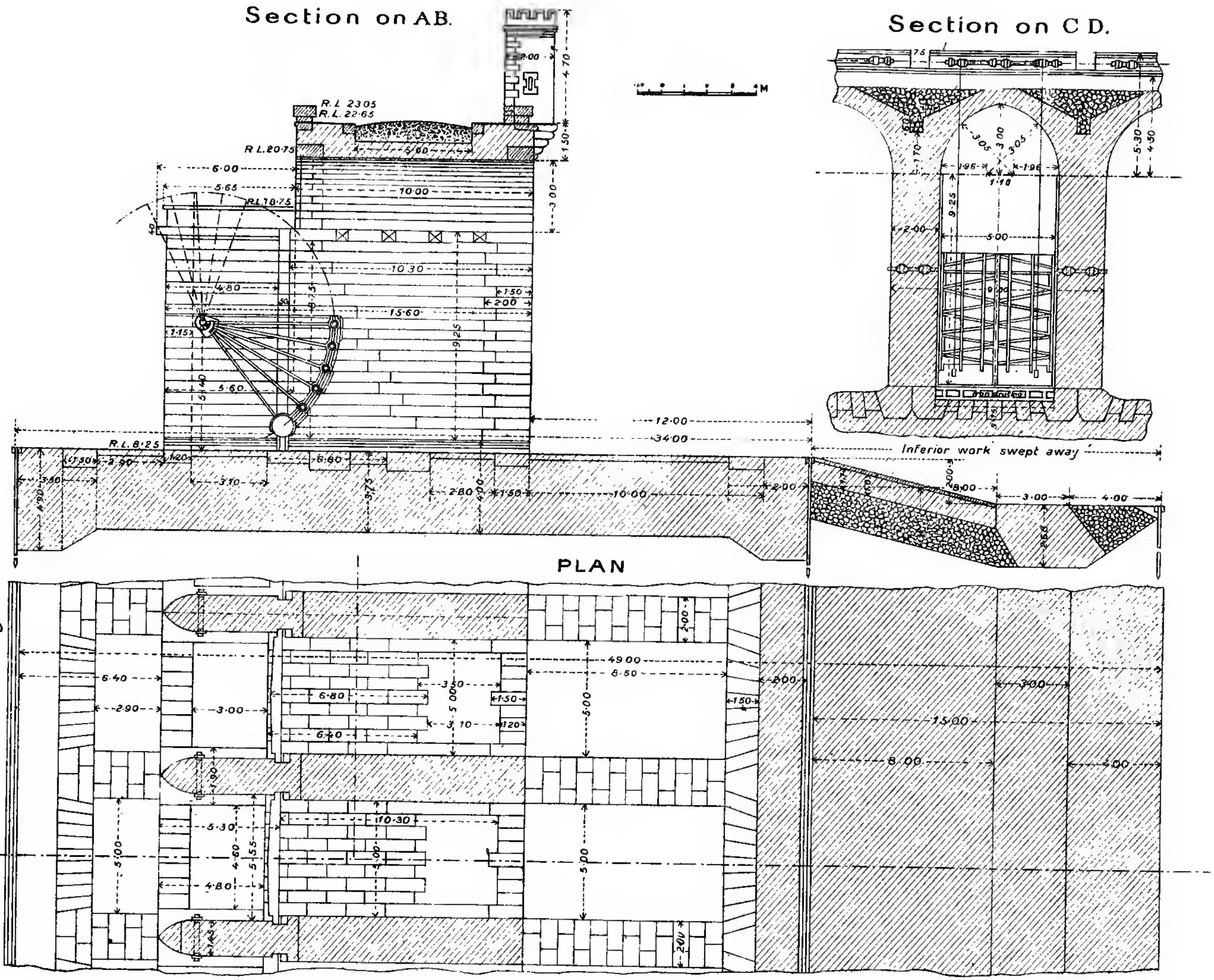
The system was so complicated that there was practical unanimity among all the writers of the many Reports on the Barrage as to the advisability of substituting a more simple system sanctioned by past experience. Nevertheless, forty-seven out of the sixty-one openings of the Rosetta Barrage had been fitted with this complicated form of gate. The remaining fourteen were regulated by vertical wooden piles resting against oak horizontals, probably as a temporary measure until the iron gates should be supplied. Both these forms of closure may be seen on Plate XI.

As was to be expected, the ingenuity displayed in the iron gates was misplaced; the gates would not work without the persuasive power of a powerful winch. These gates have been replaced since 1884 by more simple and more efficient ones. The hollow ribs of the original gates may now be seen scattered about the country, serving as land boundary pillars and kilometre posts; and parts of them were utilized as pontoons during the construction of the Weirs described in Chapter V.

The new system of regulation, adopted in the restored Barrage, consists of wrought-iron gates provided with rollers sliding in cast-iron grooves fixed in the piers. Since, before the Weirs were built, the maximum depth of water on the floor, when the Barrage was being regulated on, was 4½ metres (14½ feet), each opening was given double grooves and two gates, of which the upper one was always 2½ metres high, and the lower one in the Damietta Barrage 2 metres. In the

PLATE VIII

# THE BARRAGE
## as originally built



Rosetta Barrage the height of the bottom gate varies from 2½ to 1 metre in height on account of the floor having been raised to different levels during the repairs. In one arch, No. 9, there is no bottom gate at all, the floor level being at R.L. 11·50. The top of the upper gates, when the Barrage was closed, was, before 1900, at R.L. 14·00, and of the lower gates at R.L. 11·50 throughout.

In Chapter V concerning the subsidiary Weirs, it will be pointed out why, in 1900, the top gates of both Barrages had an additional height of one and a half metres added to them, so that the top of the gates, when fully down, is now at R.L. 15·50.

The gates are lowered and raised by means of powerful crab winches (of which there are now three to each Barrage) travelling on continuous rails.

Plate VIII from "Egyptian Irrigation" by Willcocks, gives details of the Barrage as originally built, or intended to have been built. Plate IX gives a section of the Barrage laid down as that to be worked to during the restoration. The type had often to be departed from during the work to suit the special conditions met with.

For record's sake I give below the varying levels of the floor on the Rosetta Barrage:—

At R.L. 9·00.—No. 19 to 22, 24 to 25, 27 to 45, 55 to 61.
R.L. 9·20.—No. 46 to 54.
R.L. 9·50.—No. 1 to 6, 12 to 18, 23 and 26.
R.L. 10·00.—No. 7 and 11.
R.L. 10·50.—No. 8 and 10.
R.L. 11·50.—No. 9.

The floor of the Damietta Barrage is at R.L. 9·50 in every archway, except Nos. 60 and 61 in which the floor level is R.L. 10·00.

The arches, throughout this account, are numbered from west to east.

In Chapter I it was shown that the east half of the Rosetta Barrage was founded on a mass of rubble stone tipped into the water to fill up the deep channel of the river. In several of the Reports on the Barrage a fear was expressed that, when it was subjected to a head of water, a flow would take place through the unfilled interstices of the rubble heap. This, however, does not now at any rate take place, as the Nile deposit has staunched this mass of loose stone, and it is not improbable that this section of the Barrage had become the most secure portion of the whole construction even before the cement grouting process (to be described in Chapter IV) had been applied to the foundations, whereby, there is little doubt, they were further strengthened and staunched.

# CHAPTER III.

## HISTORY OF THE BARRAGE FROM 1884 TO 1894.

A new period in the history of Egyptian irrigation began in May 1883, when Sir Colin (then Colonel) Scott Moncrieff came to Egypt, and the Irrigation Department and Works were entrusted to him to be put in order, with the satisfactory results recorded in various publications since that date. But this account is concerned with the Barrage alone, and the temptation to digress and tell of what the Department, organised by Sir Colin, has done, must be resisted.

The Public Works Ministry had just concluded a contract, to last until 1915, with a private Company to supply irrigation to the Western Delta at a cost of about £50,000 per annum; and the first thing Sir Colin had to do was to pronounce on a proposal to extend the application of this system of irrigation by means of pumps to the whole of Lower Egypt at an initial cost of £700,000 and an annual outlay of £248,550.

Hitherto there had been differences of opinion as to the relative merits of the two systems of providing for the irrigation of the Delta—by means of the Barrage, or by pumping. But, at the time of Sir Colin's arrival, unanimity seems to have been established, and all, English as well as foreign engineers, warned him to have nothing to do with that unsound work. Sir Colin, however, with his Indian experience to influence him, was not satisfied with the soundness of these conclusions, and, before accepting the extravagant programme of pumping stations, he felt that he must be certain that the Barrage was the worthless failure it was represented to be.

In December 1883 therefore, when Mr. Willcocks came from India to join the Egyptian Irrigation Service, Sir Colin stationed him at the Barrage to apply his enthusiasm and recognised ability to the task of testing the work and determining what it could be called upon to do. Mr. Willcocks found the closing apparatus in very bad order;

the staff, though large, quite incapable of doing anything beyond drawing their pay, and appliances and tools almost entirely wanting; the stone pitching below the Barrages had never been completed and the Damietta Branch had no gates at all. Mr. Willcocks set to work to remedy or remove these defects, expending £E.25,611 in so doing during 1884. As the river fell, first one and then the other Barrage was closed, this being the first time that the Damietta Barrage had ever been regulated on at all. The result of these operations was that, in June 1884, 2·20 metres (7 feet 2 inches) of water was being held up on the Rosetta Barrage and about 0·95 on the Damietta, obtaining thereby a command of water of about one metre more than the average, which, however, was due in part to a favourable summer Nile. Not only was an abundant supply of water thus obtained for all the lands irrigated by the Delta canals, but the water was delivered at a higher level, and such enormous savings in canal clearances were effected that the idea of abolishing the Corvée was entertained for the first time. The maximum head ever held up before by the Rosetta Barrage was 1·75 metres (5 feet 9 inches), and this was only for a short time.

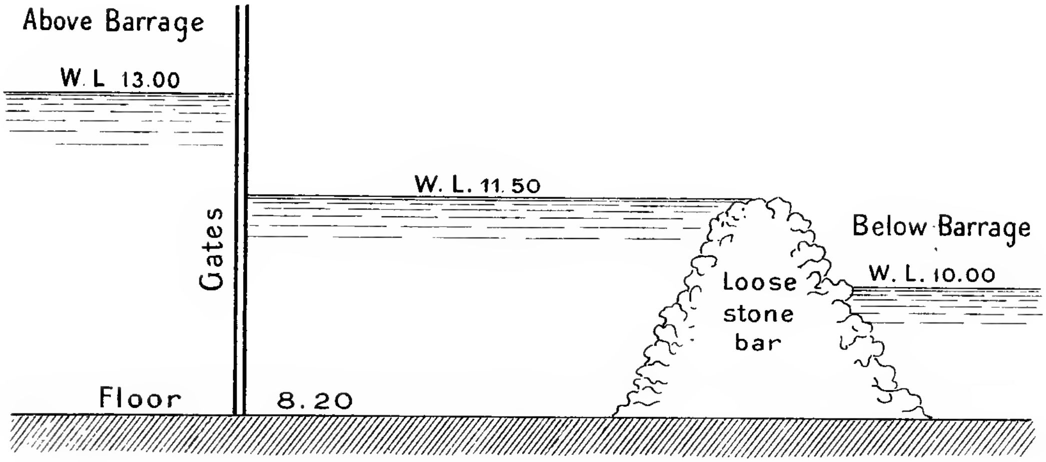
Previous to 1884, the cotton crop had given the greatest outturn in 1879, when the Nile at Aswan at its lowest was 1·39 metres higher than in 1884. The outturn in 1879 was 3,186,060 kantars or cwts.; in 1884 it was 3,630,000 kantars. The result, therefore, of the first year's experiment was satisfactory and encouraging.

In 1885 the summer Nile was a low one. But the Barrage was this year made to hold up as much as 3 metres (9 feet 10 inches) on the Rosetta Branch and 1·76 metres on the Damietta Branch, and this gave the canals an increased level of 10 centimetres over the supply of 1884. But an unpleasant reminder of the warnings to leave the Barrage alone occurred on the 21st March, when a widening of the cracks was observed in arches No. 7 and 8 of the Rosetta Barrage, and there was a downstream subsidence of the old cofferdam put in years before to protect this most doubtful part of the work. Masses of stone were thrown in round the cracked portion, so as to take the strain off it as much as possible. Just previously to this the head on the work had been divided into two by forming a bar of rubble on the floor of the Barrage as shown in the diagram Fig. 7, so as to oppose more weight to the increased horizontal thrust.

This bar contained 26,100 cubic metres of stone and cost £E.7,627. The bar was removed in July and utilised in the downstream apron of the Barrage. The sum spent on this year's operations was £E.18,246.

*Fig. 7*

DIAGRAM TO SHOW BAR ON FLOOR



In 1886 the manner of working the Barrage and the results were much the same as in 1885. During this period of experiments—1884 to 1886—Mr. Willcocks, (who was also responsible for the irrigation of the two Central Provinces of the Delta,) had Mr. Arnold Perry to assist him as Resident Engineer at the Barrage.

While temporary measures were being successfully employed by Mr. Willcocks to make the Barrage do its duty to a greater extent than hitherto, steps were being taken to provide ways and means for its permanent restoration. In 1885 a loan of a million pounds sterling was obtained for irrigation works, of which the most important was the Barrage Restoration. Lieut. Colonel Western came the same year from India to direct the works which were to be built with the Million, and he brought with him the late Mr. A. G. W. Reid, who was afterwards specially charged with the Barrage.

Before describing what was done to the Barrage, it will be as well to explain what system it was decided to adopt. As a result of Mr. Willcocks's experiments with the Barrage in 1884 and 1885, it was resolved first that the irrigation of Lower Egypt should be carried out on the general scheme laid down by Mehemet Ali, which consisted in raising the Nile level by means of Regulators and producing a natural flow of water into the canals. The rival proposition to raise the water artificially by pumping from the river into the canals was rejected.

The next question to be settled was:—Should the Barrage itself be repaired and strengthened, or should new works be constructed to do the work which the Barrage had been designed to do, but had hitherto failed to accomplish?

For some time after their arrival Colonel Western and Mr. Reid thought the task of restoring the existing Barrage so unpromising that they were inclined to favour an entirely new work, and estimates were framed accordingly. But after some hesitation and the examination of alternative proposals, it was finally decided not to abandon the old Barrage, if it were found possible to repair it. To settle this point, it was considered necessary to get down to the floor and find out its actual condition; which was not so easy to do under the 4½ metres (15½ feet) of water which covered it. Still this was successfully accomplished in 1886 by the simple plan of forming earth banks above, below and across the Barrage to enclose twenty arches at the west end of the Rosetta Barrage, and pumping the water out of the enclosed space. Within this space the bed of the Nile and the Barrage floor were laid dry without excessive pumping, although they were about 5 metres (16 or 17 feet) below the surface of the water outside the banks not fifty yards off (*see* Fig. 8).

In consequence of what was then seen of the foundations of the Barrage, it was decided to undertake its restoration, and it therefore remained to lay down the lines on which the restoration should be carried out. Under a head of water there was danger of the fine sand and mud, on which the Barrage, as constructed, was founded, being forced out from under the floor, and of the work failing from being undermined. The problem, then, requiring solution was how to make the Barrage into an impermeable bar across the river, under which water, acting with the force due to the head it was desired to maintain, should not be able to make its way.

Sir John Fowler's proposal of a deep and massive down stream curtain wall was rejected on account of the difficulty of building it, its great cost and the danger of bringing down the Barrage in the process of sinking the wall. As deep excavations in the neighbourhood of the existing work were considered dangerous, Colonel Western decided, in preference to constructing deep curtain walls, to spread the foundations out horizontally, so as to form a broad water-tight platform. This was the system adopted by Sir Arthur Cotton in the construction of the great river dams of Southern India. It was held that the same result was obtained by wide foundations as by deep ones, provided the distance that the percolating water had to travel along the underside of the foundations was the same. If the foundations were wide enough or deep enough, the passage of the water would be checked to such an extent that not only would the water be unable to carry sand and mud away from below the work, but it

PLAN OF ROSETTA BARRAGE

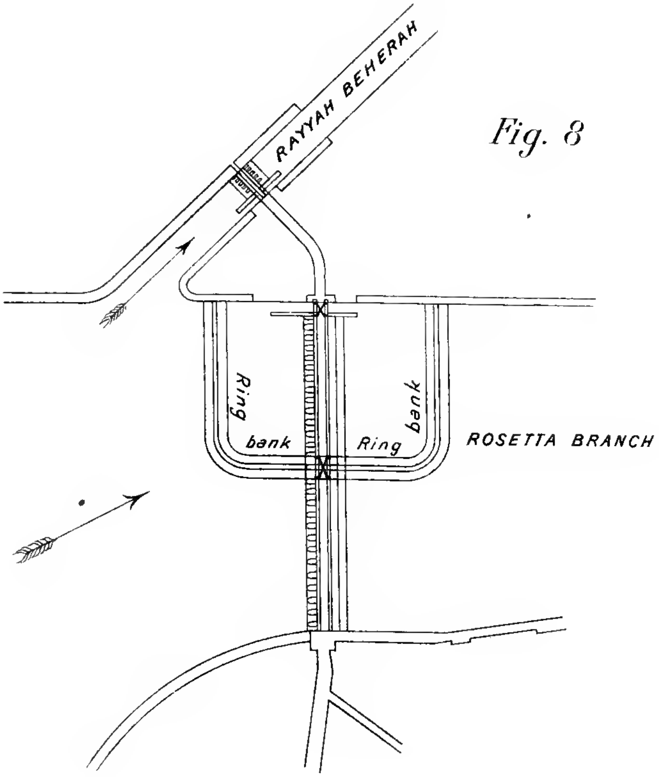
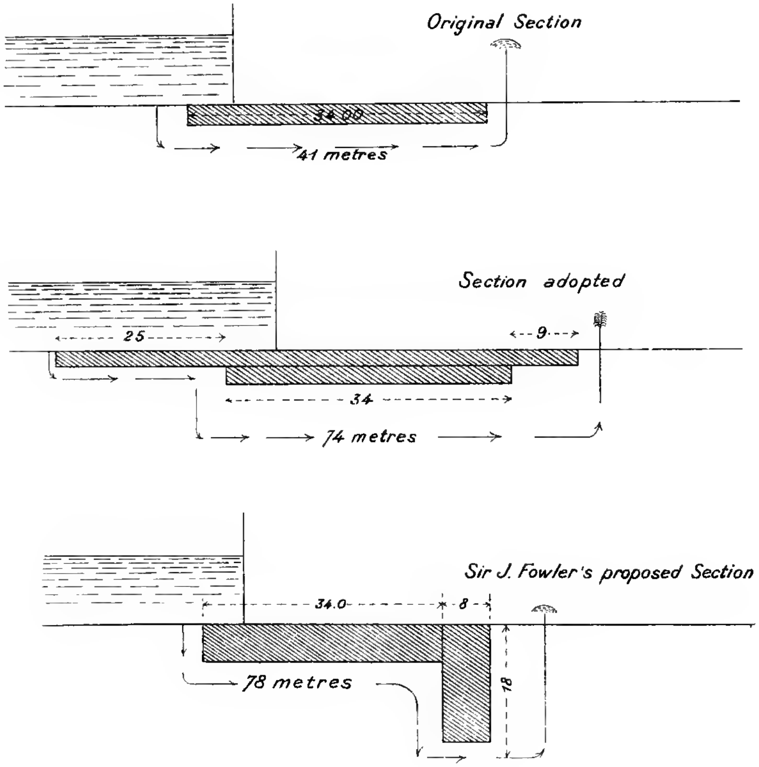


*Fig. 8*

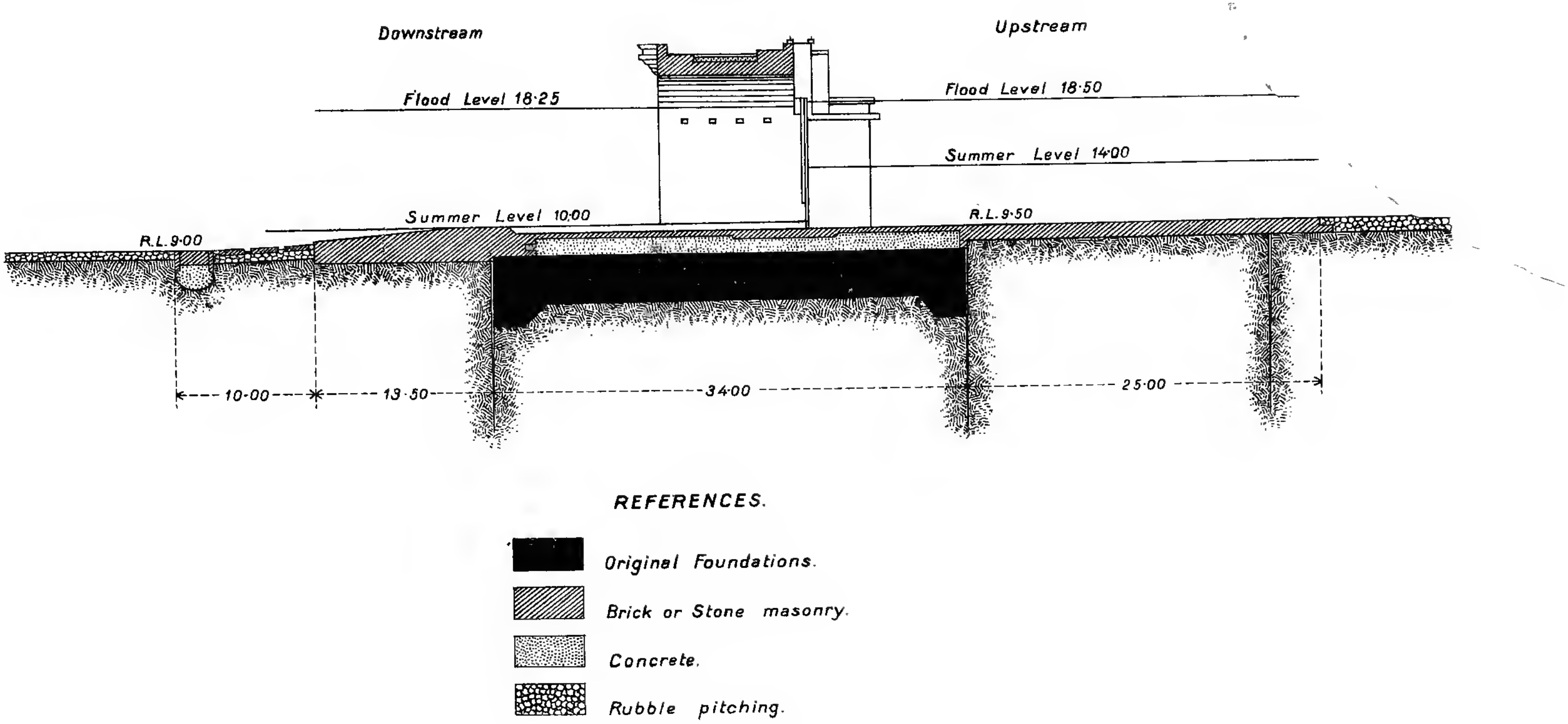
would also part with any sand or mud it might have brought with it, and so cause the substratum to become more and more impermeable. The accompanying diagrams will serve to explain this theory.

Fig. 9



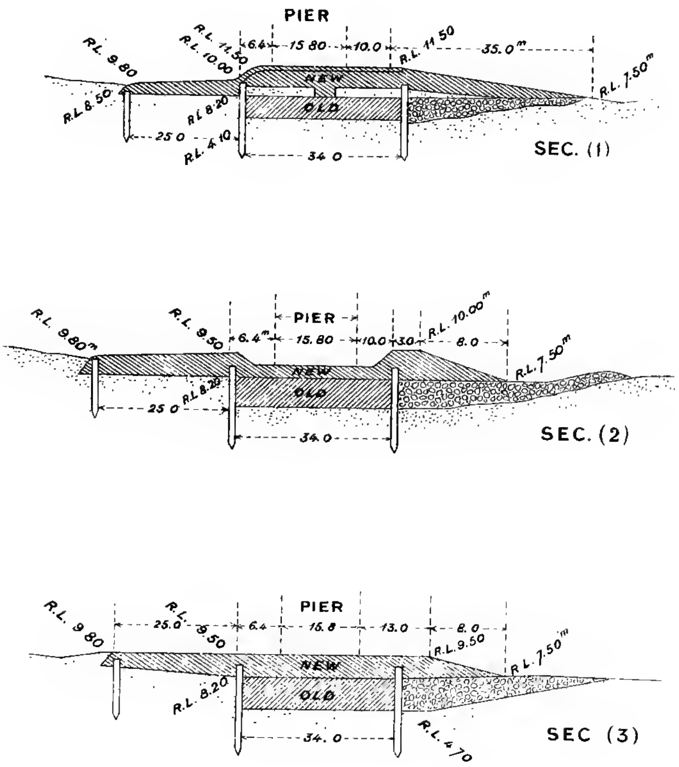
But besides adding to the width, it was necessary to give additional security to the old work. This was to be done by covering the existing floor with a layer of Portland cement concrete 1·25 metres (4 feet) thick, over which was to be laid a heavy pavement of dressed Trieste Ashlar stone under the arches and over the down stream apron, where the action was most severe. The floor was to be extended up stream 25 metres in rubble limestone masonry. Along the up stream edge of this extension a line of sheet piling, 5 metres (16 feet) deep, was to be carried across the whole river. Plate IX.

# TYPE SECTION FOR BARRAGE ADDITIONS.



This programme was generally carried out, but, where special difficulties were met with, the new flooring often exceeded 2 metres (6½ feet) in thickness. See Figure 10, which shows by typical cross-sections how the work was actually executed. The difficulties of the work were much increased by the necessity of using the Barrage to hold up water for irrigation all the time work was going on, the strength of the springs to be dealt with being thereby greatly increased. Sir Colin compared the operations to mending a watch without stopping the works. The working season, moreover, between the floods was short, and in the most favourable year extended only from the 1st November to the end of June. More than two months of this period was expended in forming the ring banks, and nearly as much in

*Fig. 10*



pumping out the enclosure and making other preparations. Only four months were left for actual work on the floor, which could not generally be begun before the 1st March.

It has been already stated that in 1886 twenty arches of the Rosetta Barrage were enclosed and laid dry for the purpose of examining the floor in this, the worst section of the Barrages, with the view of enabling a final decision to be taken as to the general restoration; and that, as a result of the examination, the restoration was decided on. Advantage was taken of this opportunity to partially repair the floor under six of the arches.

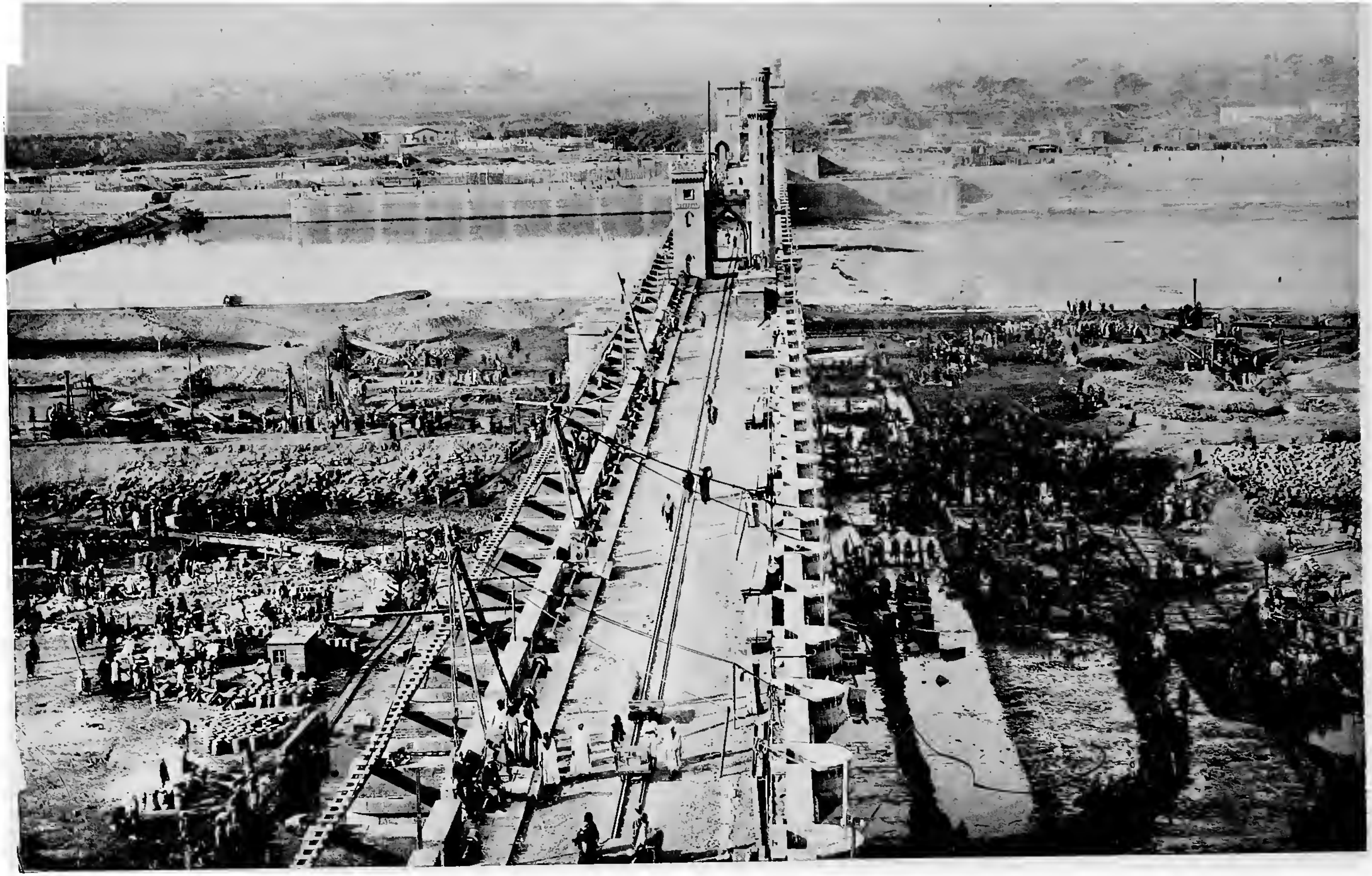
As the whole discharge of one branch of the river could not be shut off at a time, it was arranged to spread the work of restoration over four seasons, half of one Barrage being taken in hand at a time.

Sir Colin, in his "Note on the Nile Barrage, 1890," shortly describes the four seasons' work, and the following account is taken almost verbatim from his Note. A more detailed account will be found in Mr. Reid's Reports and an abridgment of the late Liernur Bey's Report, published in the Irrigation Reports for 1887, 1888, 1889 and 1890.

Work began in earnest in 1887, when the western half of the Rosetta Barrage was undertaken. The first season was the worst of the four. Experience of what was to be done was less and appliances more incomplete than in succeeding seasons, and the section of the Barrage taken in hand was in much worse condition than any other.

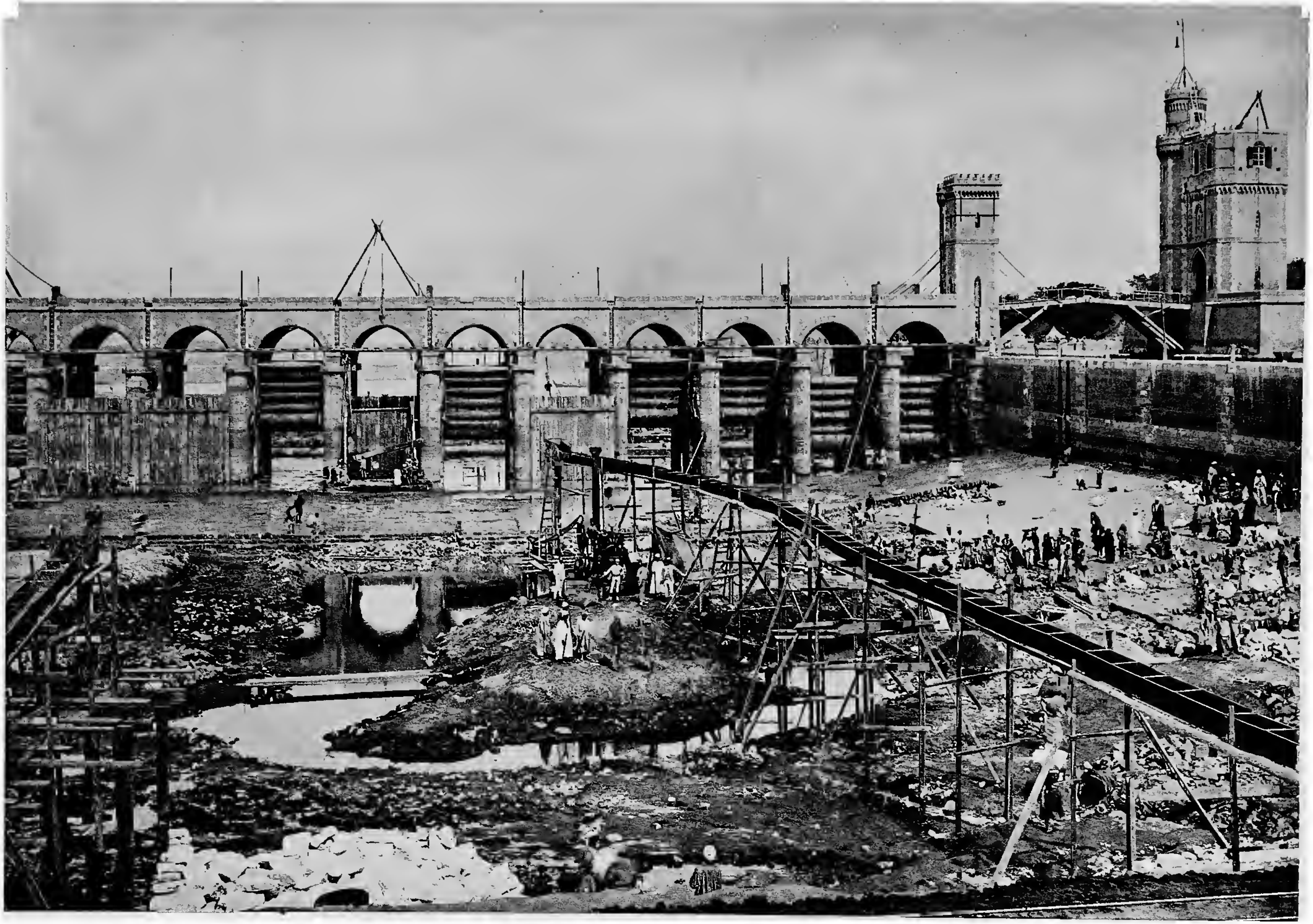
On the 2nd December 1886 the enclosing earth dams were begun: on the 24th March 1887 the first stone of the new work was laid. From the latter date work was carried on day and night, electric light being used during the night, while nine powerful steam pumps were constantly at work keeping down the water, until, in anticipation of the arrival of the flood, the last piece of machinery was removed from the completed floor on the 1st July. Before the next morning the rising flood had covered all that had been done.

During the course of the season's work fresh and unlooked for difficulties were experienced every day. A serious difficulty arose in connection with the Western Lock. It was found that the massive outer wall of the lock rested on foundations, the base of which was eight feet higher than the Barrage floor. To dry the latter, work had to go on below the lock foundations, and these foundations were appallingly



ROSETTA BARRAGE DURING RESTORATION, AS VIEWED FROM THE EAST TOWER.

(Photograph by J. Heyman, Cairo.)



ROSETTA BARRAGE DURING RESTORATION, AS VIEWED FROM THE UP-STREAM DAM ACROSS THE RIVER BED.

(Photograph by J. Heyman, Cairo.)

bad, as described by Mr. Reid in his Report. It was only with difficulty that the lock wall was prevented from falling over bodily.

In the Barrage itself it was found that the floor, as well as the arch of one opening, was cracked across diagonally, showing a complete fracture of the work, the fissure being four inches wide. Strong springs burst out daily in fresh places, and had to be staunched at an immense expenditure of material. Daily Mr. Reid had to face some new trouble and to invent some new expedient, and he was always equal to the occasion. The result of the season's work was satisfactory, and established confidence in the ultimate success of the restoration.

In 1888 the eastern half of the Damietta Barrage was attacked, and the work proved to be easier than that of the preceding season. The earthen dams were begun on the 1st December 1887, and the repairs to the floor on the 9th March 1888. The condition of this Barrage was much better than that of the other, but it seemed that this was so, only because the work had been less tried. There was the same inferior and careless work. The floors of some of the arches were quite unfinished, and if the gates had ever been put in place and subjected to pressure, the effect must have been as disastrous as in the case of the Rosetta Barrage. By the 20th June, when this season's work came to an end, forty-one arches had been put in order.

After the deficient flood of 1888 the river fell fast, and as early as the 2nd November the earth dams were begun to enclose the eastern half of the Rosetta Barrage, which still remained to be repaired. This was the section of the Barrage which had been built on a mass of loose rubble. It was a fortunate thing that the dams could be begun so early, as they had to be formed in water which, over a length of 100 yards, averaged 40 feet in depth. This season's work was the easiest and least eventful of all, and was completed in good time in June 1889. Plates X and XI are photographs of this season's work, taken by J. Heyman, Photographer, Cairo.

In November 1889 the last season's work began. It was expected to be a very easy one, but proved otherwise. There did not appear to be very much to do, since, of the seventy-one arches of the Damietta Barrage, forty-one were already finished, and it had been resolved to cut off and close the ten arches together with the lock at the west end of the Barrage, as it was found that the extra waterway, provided by them, was in excess of what was necessary or even desirable.

There were only twenty arches then to repair, and the work seemed advancing very fast, when suddenly a powerful spring burst out in the half-repaired floor, and it was found that a rush of water was finding its way, from a point in the river outside 70 metres distant, under a portion of the new flooring laid in 1888. This spring, throwing up mud and sand, soon drowned out the pumps. Mr. Reid promptly cut his enclosure banks and flooded the whole area. The action of the stream had washed out the treacherous soil below the new upstream apron and a considerable portion had settled as much as four feet. Mr. Reid then threw up new banks, so as to isolate the unsound parts, and, little by little, with great precaution and frequent checks, he repaired all the mischief.

On the 16th June 1890 he reported that the Barrage below water-level was finished. Four seasons' anxious work was at an end, and the Barrage was pronounced to be capable of holding up four metres of water. The work was then placed under Mr. E.W.P. Foster, with M. Liernur as resident engineer. It will be pointed out further on what it has actually done.

The total cost of this restoration for both Barrages was £E.465,000. The quantities of masonry executed were:—

| | Cubic metres. |
|---|---|
| Concrete ... ... ... ... ... ... ... ... ... ... ... ... ... ... | 23,863 |
| Rubble masonry ... ... ... ... ... ... ... ... ... ... ... | 54,411 |
| Ashlar masonry ... ... ... ... ... ... ... ... ... ... ... | 6,983 |
| Brick masonry... ... ... ... ... ... ... ... ... ... ... ... | 2,680 |
| Dry rubble pitching ... ... ... ... ... ... ... ... ... ... | 25,460 |
| Total of all sorts... | 113,397 |

The restoration, though complete, was not to put an end to all anxiety for the Barrage, and Mr. Foster was to have his trials. The accident of the 1890 season left a serious defect behind it, which declared itself as soon as the head on the Barrage became considerable. In May, 1891, when the Damietta Barrage was holding up 3·18 metres of water, seven springs appeared along the downstream edge of the masonry floor opposite bays 20, 21, 22, 25, 26 and 37; and it was ascertained by experiments that these springs arose from water which was passing under the floor from upstream of the Barrage. A large inlet was discovered in front of bay 29-30. The inlet crater was filled

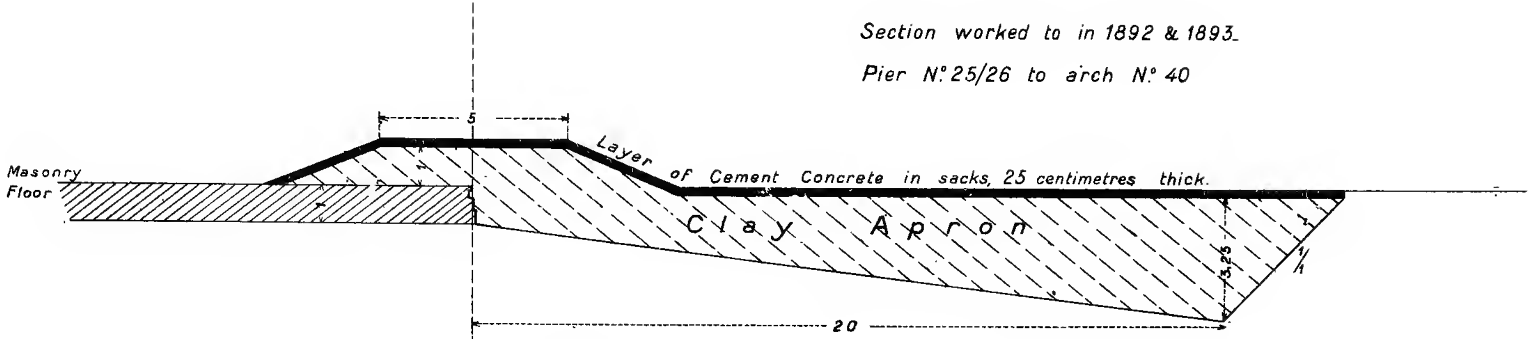
PLATE XII

# DAMIETTA BARRAGE, UPSTREAM CLAY APRON

Dimensions in metres

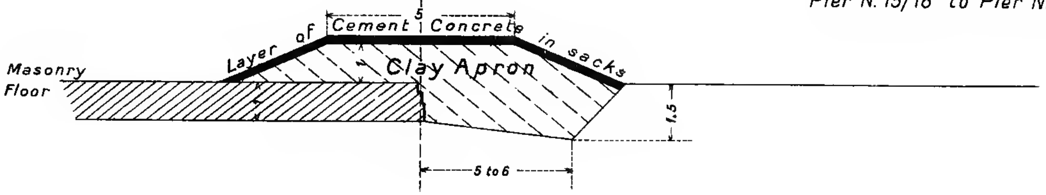
*Section worked to in 1892 & 1893.*

*Pier N° 25/26 to arch N° 40*



*Section worked to in 1894.*

*Pier N° 15/16 to Pier N° 25/26*



Note. *The work of 1892 (Pier 25/26 to arch 35) was not consolidated by the sledge, except that part of it which was taken up and relaid in 1893.*

with sacks of sand and an island of soil formed over it up to water-level, and the upstream apron floor was also covered with soil. This weakened but did not stop the springs, as the soil was too light, but further work had to be postponed till the next season.

The following system for stopping the leaks was eventually adopted by Mr. Foster, after consulting with Colonel Western. A trench of the dimensions given in the accompanying diagram (Plate XII) was cleared of its rubble pitching and porous soil by dredging along the upstream edge of the floor in front of from three to five bays at a time. This trench was then filled with stiff clay deposited in layers of half a metre thick, pressed down by means of a sledge drawn over it, to form an impervious curtain. Over the junction between the clay and the masonry floor a broad clay bank one metre high was formed and consolidated to make a tight joint: it was then covered with a layer of sacks filled with concrete and laid close together to protect the surface of the clay from erosion by the current. Great care had to be taken that this joint was properly cleared of loose material before the clay was laid on it, and that the concrete in sacks was carefully bedded and arranged. To do this a diving bell was made use of. Careful soundings made in 1895 over the whole area of concrete sacks showed that they had not been displaced by the flood.

In 1892 and 1893 a bank had been made down stream of the Barrage enclosing the springs, so as to decrease the head on them by letting the water rise in the enclosed pond; but this precaution was not considered necessary in 1894, as the springs had been almost entirely staunched.

Since then, three weak springs, throwing perfectly clear water, have been found to exist down stream of arches 21 and 26, but it has been ascertained that these have no direct communication under the floor with the upstream side of the Barrage.

It may be as well here to correct what I consider to be misleading in a statement made about the Rosetta Barrage in the standard work on irrigation in Egypt. In his second edition of "Egyptian Irrigation," p. 288, Mr. Willcocks expresses his views as to the existing waterways of the two Barrages as follows:—

"The Rosetta Barrage with a mean width of 450 metres has only sixty-one openings of 5 metres each, while the Damietta Barrage, with a mean width of river of only 250 metres, has also sixty-one openings of 5 metres each. To the most casual observer of the Barrages in high flood, the inadequacy of the Rosetta Barrage is as apparent as the unnecessary length of the Damietta Barrage." Mr. Willcocks concludes that the Rosetta Barrage should have its waterway increased by an additional nineteen openings of 5 metres each.

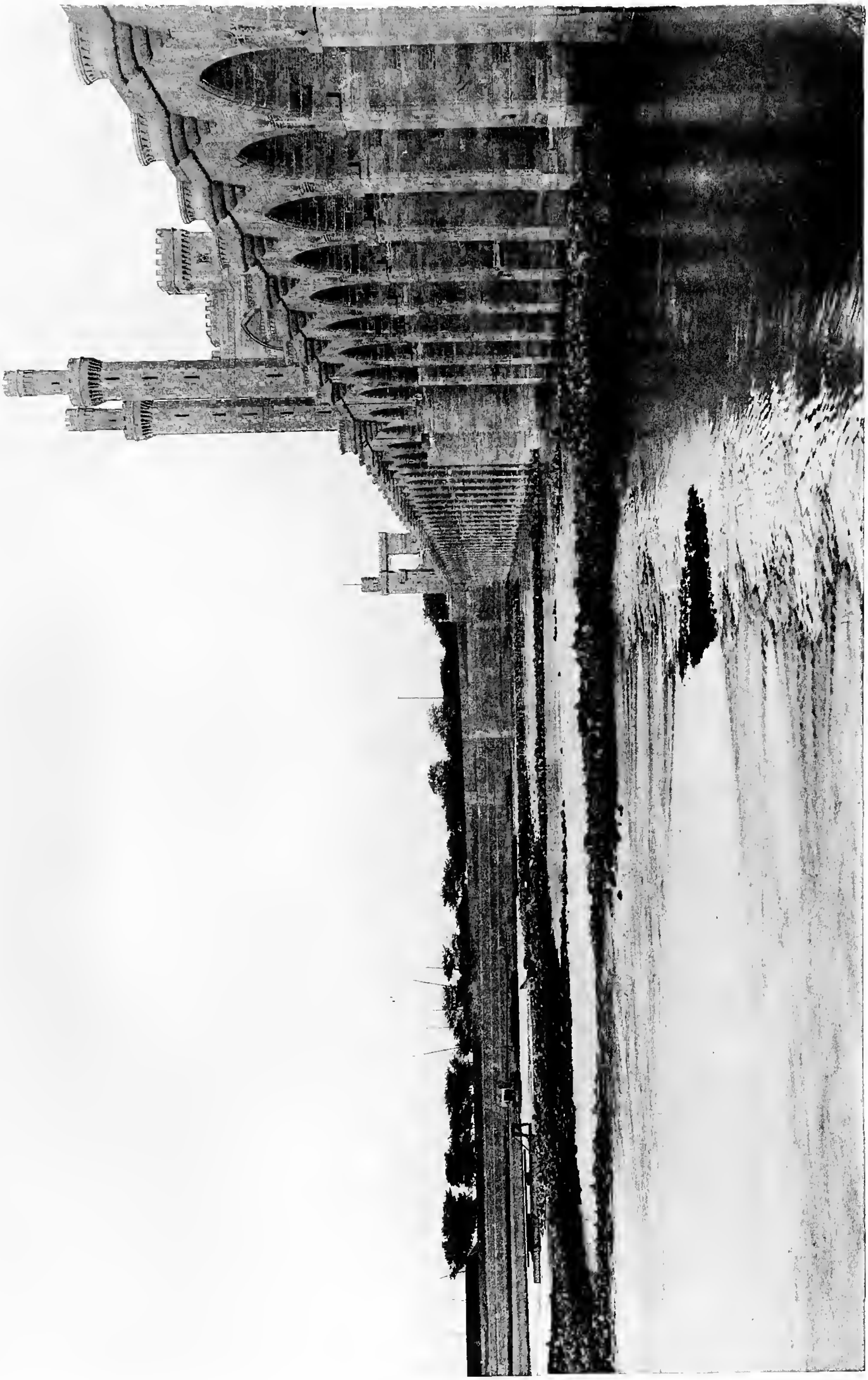
That the Damietta Barrage waterway is still, in spite of its reduction from seventy-one to sixty-one arches, unnecessarily large is shown by the silting up of from five to ten arches on the west flank, which takes place annually during flood, and by the slight action there is downstream under any conditions of head and discharge. But it is not logical to argue that, because the Damietta Barrage is too large, the Rosetta Barrage is too small. If the Rosetta Barrage waterway were insufficient, the insufficiency would be shown by the disturbance of the protective materials forming the loose apron beyond the floor, or by a scouring out of the river bed beyond the talus, though this latter effect would rather show that the protective apron was not long enough. But there are no such effects produced. Since the restoration of the Barrages was completed in 1890, no addition or repairs to the talus pitching have been necessary, and there has been no disturbance of stones of even small size. This has been ascertained by actual vision when the floors were laid almost dry in 1899 by careful caulking of the Barrage gates. Lest any one should be inclined in the future to question this statement, I took photographs of the downstream views of both Barrages in 1899 at such conditions of water-level as will never be repeated again on account of the construction of the new Weirs which pond up the water over the Barrage floors. Two of these photographs are reproduced here. The view of the Damietta Barrage (Plate XIII) was taken on 1st April 1899 when the gauge reading downstream of the Barrage gave a water-level of R.L. 10·00. That of the Rosetta Barrage (Plate XIV) was taken on 26th June 1899 when the downstream level was R.L. 9·93 and the upstream R.L. 13·93, and, therefore, when the Barrage was holding up its theoretical maximum head of four metres. The former view shows the remains of the banks of stone already referred to as having been made in 1892 and 1893 to enclose the springs.

The facts are that, with a high flood level of R.L. 18·31, the Rosetta Barrage has, since the restoration, a waterway of 2,767½ square metres.

PLATE XIII.

VIEW OF TALUS OF DAMIETTA BARRAGE.

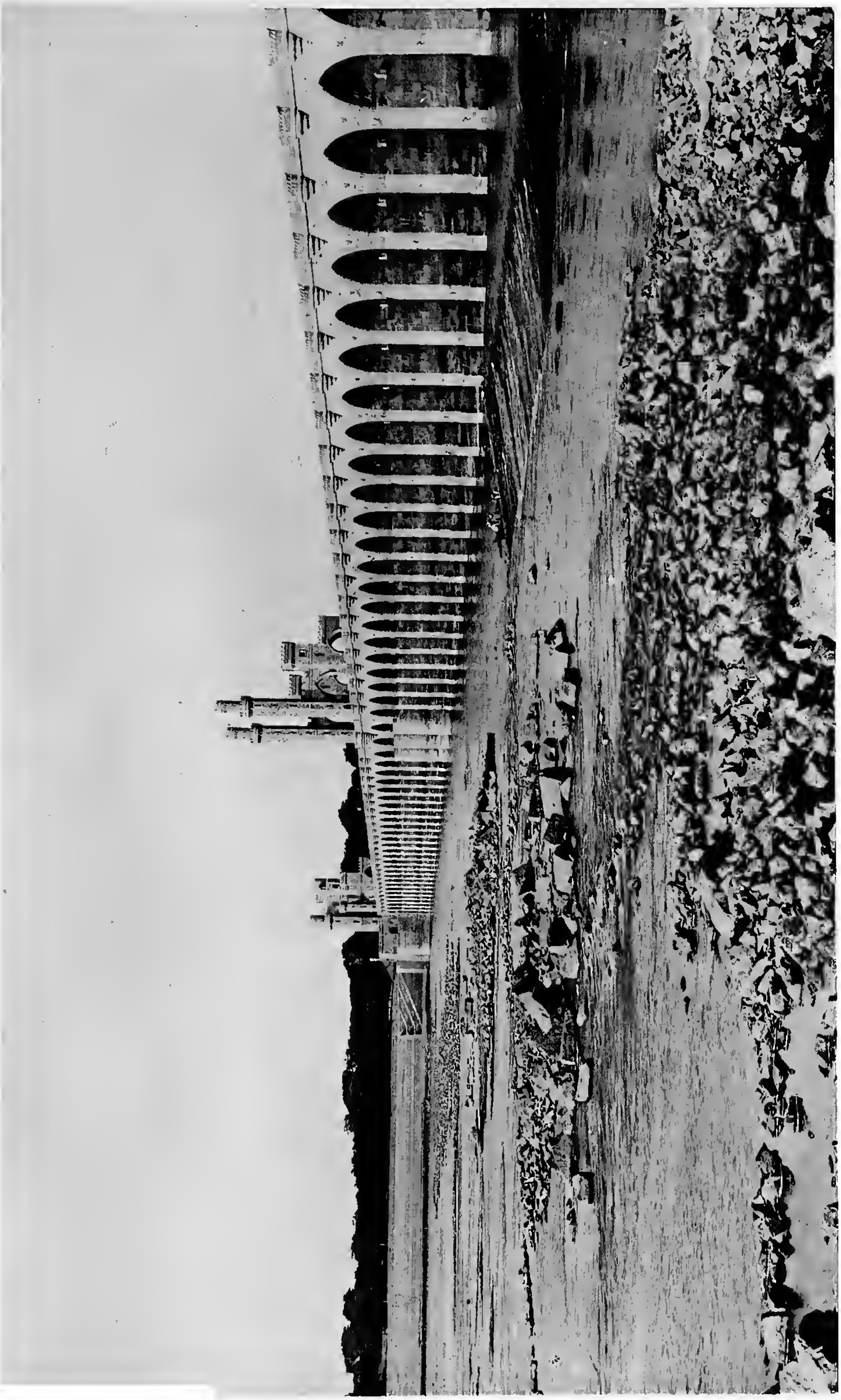
(Photograph by the Author.)



DOWN STREAM VIEW OF DAMIETTA BARRAGE.

VIEW OF TALUS OF ROSETTA BARRAGE.

(Photograph by the Author.)



DOWN STREAM VIEW OF ROSETTA BARRAGE.

The discharge at high flood is 6,505 cubic metres a second, so that the mean high flood velocity between the piers is 2·35 metres a second. The afflux is 22 centimetres. And under these conditions there has been no disturbance of the talus or scouring of of the river bed beyond, (*see* Plate XIV).

# CHAPTER IV.

## CEMENT-GROUTING OPERATIONS FOR FURTHER SECURITY OF THE BARRAGE FOUNDATIONS.

DURING the flood season of 1892, while there still remained to carry out two seasons' work on the clay apron addition to the upstream floor of the Damietta Barrage, Sir Colin Scott Moncrieff retired from the Egyptian Service, and Mr. (now Sir William) Garstin succeeded him as Under Secretary of Public Works. A month earlier, Colonel J. C. Ross, Inspector General of Irrigation, had also retired and was succeeded in Lower Egypt by Mr. E. W. P. Foster. The Barrage was thus, henceforward, committed in trust to new hands so far as the Chief of the Service was concerned, while Mr. Foster, with Liernur Bey under him, remained in immediate charge as before. These changes were followed by others in 1894. Liernur Bey, who had been a most careful nurse to the Barrage, died while on leave; and Mr. Foster, shortly after, retired from the Service, feeling more regret at parting with the Barrage than with any other part of his charge. The author succeeded Mr. Foster as Inspector General, and Mr. E. Mason (whose connection with the Barrage has been longer and more intimate than any other official's) filled Liernur Bey's place temporarily, until Mr. Allan Joseph relieved him towards the end of 1895.

During this period of changes of staff, nothing beyond the completion of the clay apron was attempted with the object of making the Barrage more secure. But, at this time, a change (which the yellow primrose variety of visitors to the Barrage may consider as all-important) was brought about in the appearance of the grounds separating the two Barrages. After the restoration, these waste spaces were covered with the scattered remnants of building materials, and were chequered with pitfalls and stumbling-blocks. Mr. Foster and Liernur Bey effected much in tidying up what was untidy, and in levelling up low places where mosquitoes multiplied. But it was left for Mr. Walter Draper F.R.H.S. (who was engaged at the end of 1895) to apply his talent

PLATE XV.

VIEW IN THE BARRAGE GARDENS.

(Photograph by the Author.)

for landscape gardening to the Barrage grounds, and to change thereby the bareness that he found into the delightful gardens which now add to the Barrage a charm such as bricks and mortar alone could not display. A view of a recently laid out portion of the grounds is given on Plate XV.

During the years 1895 and 1896, nothing was done to the Barrage beyond watching the springs and examining the floor, and no fresh signs of insecurity were detected. But for all that, a sense of security was still wanting.

A perusal of the foregoing chapters—which bring the history of the Barrage up to the end of 1894—will probably lead the reader to the conclusion that, though the Barrage had been made to perform its duty, the desired result had been brought about in spite of the facts that its floor and foundations rested on a treacherous subsoil and that they consisted of patchwork, the subsequent additions to the original structure having been formed about an unsound nucleus, the radical defects of which necessitated those additions; so that the resulting work had little that was homogeneous about it. The three springs downstream of the Damietta Barrage floor, which up to 1896 were still yearly detected, as well as an old spring opposite arch No. 5 of the Rosetta Barrage, which was looked for and found in 1896, though not of a nature to cause anxiety, still showed that there were some imperfections in the foundations or in the soil below the foundations on which the Barrage rested. Warnings had also been uttered, among them one by Sir Colin Scott Moncrieff himself, pointing out that, though off the sick list, the Barrage was still of delicate constitution, and must be handled with unceasing care and watchfulness. And, with this warning, he handed over the great responsibility of the care of the Barrage to his successor, Sir William (then Mr.) Garstin, under whose supreme direction the works, now to be described in this and the following Chapters, were carried out; and to such good purpose that a sense of security may now at last be said to have been established. But at the time that the warning was penned, a just appreciation of the immense importance of the Barrage to Lower Egypt, and a knowledge of the defective condition of the old foundations that lay under and within the later additions, created a feeling of uneasiness and apprehension in the minds of those who were responsible for the safe-keeping of the work. Hence any proposals tending to remove the causes of this uneasiness were welcomed, though, in the opinion of some, it were better to leave well alone. On this principle of leaving well alone no work with the view of strengthening the foundations was undertaken in 1895 and 1896.

But, in the spring of 1896, Sir William Garstin arranged with the late Mr. W. R. Kinipple, M.I.C.E., that he should come to Egypt to advise the Egyptian Government on the question of applying his system of "Stock-ramming" to two locks on the Ismailiyah Canal which had shown unmistakeable signs of failure of foundations; and advantage was taken of his presence in Egypt to consult him as to the practicability of applying his system to the Barrage so as to make it sufficiently secure to remove all doubts as to its permanent stability. His report encouraged the hope that its application might succeed.

Soon after Mr. Kinipple had been asked to give his advice, some slight hair-cracks appeared in arches Nos. 7 and 8 of the Rosetta Barrage, but after their first appearance they did not enlarge. No doubt the appearance of these cracks, whatever may have been their cause, removed any hesitation that might have been felt as to the desirability of giving Mr. Kinipple's system a trial as a means of making the foundations of the Barrage secure.

Sir W. Garstin, therefore, decided to commence work after the flood of 1896 and to experiment on eleven arches of both Barrages opposite the springs which were known to exist. If the springs had been thereby stopped and the operations had proved otherwise satisfactory and successful, the rest of the two Barrages were to have been similarly treated. The Egyptian Government was fortunate enough to secure the services of Mr. Kinipple himself for superintending the first season's experimental work.

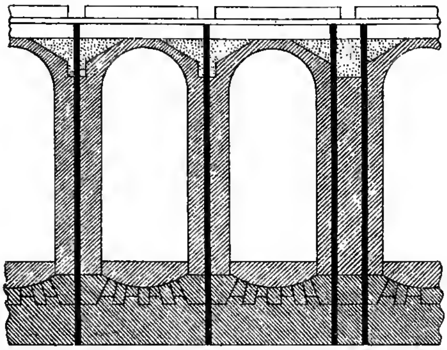
The system of "Stock-ramming," as applied to the Barrage, consisted in forcing plastic clay under pressure down holes bored in the thickness of the piers to the underside of the floor. Mr. Kinipple was confident that the pressure would cause the clay to spread itself out under the floor and foundations, and displace the shifting sand met with, or render it so compact as to make it capable of resisting without leaks the maximum water pressure desired.

Three vertical holes, situated 3½ metres apart on the longitudinal axis of each pier, were to be bored down to the underside of the lowest layer of the foundations. These holes were then to be lined

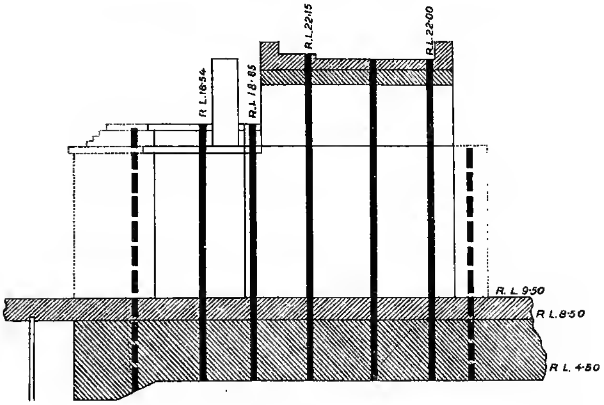
# DIAGRAM

## Showing bores made in the Barrage piers

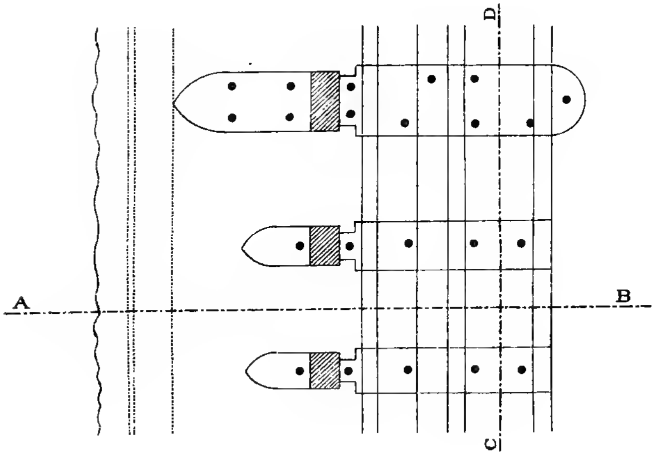
Section on C.D.



Section on A.B.



Plan



with iron tubes, and the clay, formed into pellets, to be passed down them, and be subjected to pressure. It was hoped that the clay from adjacent piers would meet under the flooring between the piers and there unite so as to form a continuous water-tight curtain wall under the centre of the Barrage.

But this hope was not realised on the eleven piers of the Damietta Barrage which were selected for the experiment. No amount of ramming sufficed to make the clay spread laterally from the bottom of the bore to the extent desired, as was conclusively demonstrated both by experiments in the workshops and observations on the Barrage itself.

But though stock-ramming with clay was not successful, the idea of getting at the defects in the foundations by boring, and compacting what was loose by the introduction of material under pressure by way of the bores, was not abandoned. The alternative method—which it was perhaps a mistake not to have adopted in the first instance—was to employ cement grout instead of clay, and to obtain the pressure for inducing it to spread in all directions from the weight of the column of grout itself. The continuous steady pressure of the column of grout was a much preferable form of force to the intermittent blows of a falling weight, for it was less likely to do harm to the masonry of the Barrage.

The accompanying diagram (Plate XVI) will explain the process. Holes were first bored as shown by the strong black lines, and cleared to at least one metre below the lowest level of the foundations. The cement grout was then poured into the bore, and the pouring continued until the grout filled the bore to the level of the roadway or pier-tops. When the bore was full, the pressure exerted by the column of cement at the bottom of the bore was, in the case of the bores made from roadway level, 26 tons per square metre (2·4 tons per square foot); and, in the case of the two others, 19 tons per square metre (1·76 tons per square foot). So great a pressure was sufficient to force the cement into all cavities in communication with the bore, so that the grout must first have enveloped all loose material, and then, by its property of setting, have compacted it into a solid mass. That the cement *did* set we know, as in some instances it was brought up in a hard state, when clearing the bore to which it had travelled from below the floor.

The first experimental season's work, carried out in January 1897, was so encouraging, that it was decided to apply the system to the whole of the two Barrages. The detailed account of the operations and the record of the observations made are to be found in the Irrigation Reports of the years 1896, 1897 and 1898. Altogether there were bores made to the underside of the foundations at 680 different points, and, in each of these the levels and thickness of the different materials passed through were noted, as also the material of the river bed underlying all. Generally speaking, what had been before stated as to the condition of the foundations, was confirmed. The fifteen bays on the west of the Rosetta Barrage, where the Barrage failed in 1867, were found to be built over a foundation consisting of two to three layers of concrete separated from each other by intermediate strata of sand from half a metre to a metre thick. The same was the case with the eight bays immediately to the west of the central piers. The worst condition of things was found under bays Nos. 6 to 9, where there existed what appeared to be extensive cavities in the thickness of the foundations, through which the boring tool fell without meeting with any resistance. The cavities were from a metre to half a metre deep, and apparently extended under the piers the whole width of the roadway. The eleven bays on the east were found to stand over rubble, and it was here that the greatest expenditure of cement took place, the record-beating numbers being 158 barrels for one hole, and 439 for the five holes of one pier. The bed below the rest of the Barrage was generally clean and fairly coarse sand. Where the foundations were not separated up into disjointed strata with intruded layers of sand, it was found that the foundation level was generally at R.L. 4·70. Probably the lowest layer did not retain much of its mortar.

The Damietta foundations were found to rest generally on a uniform bed of sand at the average level of R.L. 4·12; but five bays towards the east rested on black clay. In the first season's work, when experimenting with stock-ramming, a large cavity of 25 to 80 centimetres height was found under the wide central pier. As the underlying concrete was found to go down to an extra depth, equal to the height of the cavity, below the general level of the foundations, it was conjectured that there must have been a hole scoured out below the floor into which the lowest layer of concrete subsided, leaving the upper masonry bridging the cavity formed. This cavity was stock-rammed with stiff clay, and subsequently again bored through, as well as the concrete below it, when the cement-grouting process was applied to the Damietta Barrage two seasons later.

During the three seasons' work an aggregate length of 12,400 metres (7¾ miles) of bore hole was jumped in the masonry of the piers and floor, and 6,094 barrels of cement were poured down the bores in the form of grout. The total cost of the whole operation was only £E.6,027. The system was not a new one, but its application to the Barrage is perhaps one of the most remarkable instances in which it has been employed. The somewhat monotonous operations were very patiently and carefully supervised by the late Mr. J. G. West.

It would, probably, not have been safe to have subjected the Barrage to this operation while it was in the delicate state in which Sir Colin Scott Moncrieff found it. For, if the risk had been run, the pressure of the cement would most likely have blown up the weak floor or forced an exit along some fault in it. The repairs before described, which were carried out under Colonel Western's direction, enclosed the unsound foundations by an outer shell of solid masonry, so that their defects were prevented from developing into dangers. The later operations of cement-grouting consisted in introducing cement-grout under pressure into and under the defective foundations with the object of filling all that was loose into one cohering solid mass.

The least that can be said of the result is that the Barrage must be stronger than it was before the cement-grouting operations, though the effect produced is out of sight, below and within the foundations. The knowledge of the fact that cement-grout under the pressure of its own column, varying from 1¾ to 2½ tons per square foot (19 to 26 tons per square metre) has been applied to about 340 points below the foundations of the body of each Barrage, is sufficient to inspire confidence that the Barrage can, henceforward, support at least a head of 4 metres, which produces only a pressure, per unit of area, of from a fifth to a sixth of the pressure exerted by the columns of cement grout at the 680 points of its application. And in fact, during the summer of 1898 after the completion of the operation, the Rosetta Barrage held up as much as 4·35 metres without showing any signs of its inability to do so, and, doubtless, it could have held up to at lest 4·50 metres, the full height of the original project, with safety.

Before, however, this fact had been observed, it had been decided to build supplementary Weirs downstream of either Barrage to lessen the maximum head which the original structure would have to hold up; and, in accordance with this decision, the construction of one of the Weirs had actually commenced.

# CHAPTER V.

## SUBSIDIARY WEIRS BELOW THE BARRAGES.

IT was a pure accident that the very first pier which was selected on the Damietta Barrage for the stock-ramming experiment happened to be the one that stood over the greatest defect that existed in the foundations of that Barrage, so far as the borings have revealed them. In fact, the centre piers were chosen because it was thought that, in consequence of an invert shown in the original design as underlying the central pier, here was the strongest point on which to begin our experiments. It was not, however, an accident that the piers of the Rosetta Barrage selected for the cement grouting experiment turned out to be over the worst portion of the foundations of either Barrage, as these piers were expressly chosen because the foundations below them were known to be bad; but, nevertheless, well suited for the experiment, as they had been enclosed in an extra thick outer casing of sound masonry by Colonel Western's work. But the unmistakeable direct evidence of the existence of such formidable defects in the foundations, revealed by the borings, had an effect which the vague knowledge that the foundations were unsound could not produce. The probing had demonstrated the correctness of Linant's diagnosis:—"La maladie le travaille intérieurement."

And as a result of what were reckoned startling disclosures, the idea of supplementary Weirs to relieve the pressure on the Barrage germinated at the time of the writing of Sir W. Garstin's Administration Report for 1896, in which it first took root in the following passage:—

"Undoubtedly the best and most efficient way of rendering the Barrage safe would be to permanently reduce the head of water thrown upon it during regulation. This could best be done by building a supplementary dam downstream of it, which would hold up water, say to two metres or two and a half metres, and thus reduce the possible difference of level upon the Barrage itself to something under two metres."

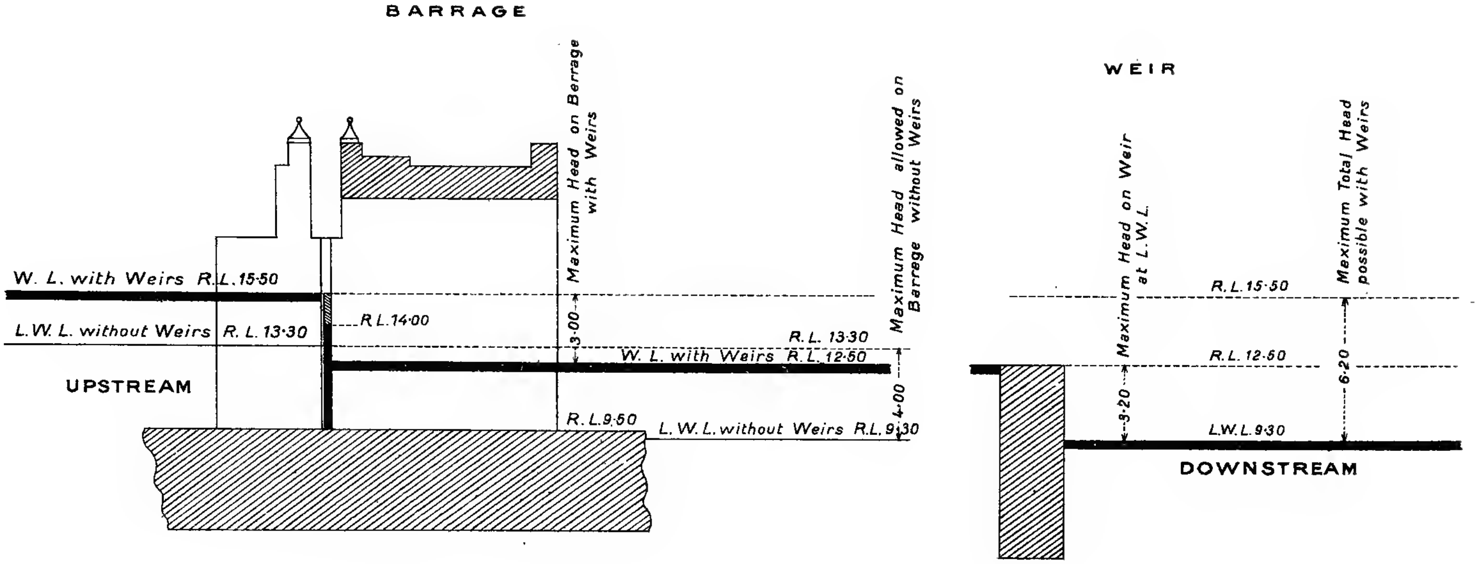
By the end of the year the idea had grown into the definite shape of a project, and Sir W. Garstin was successful in convincing the Commissioners of the Caisse de la Dette that the scheme was worthy of their support, with the result that a sum of £E. 530,000 was granted for the construction of the Weirs.

The original idea was to merely reduce the head on the Barrage to 2 or 2½ metres, and thus to gain greater security, where security was a matter of vital importance to the country. But, in studying the project, the original idea was developed to meet a yearly demand of continually increasing intensity, at the same time that the prime object of relief to the Barrage was provided for. The situation requiring attention was this :—In late July and early August the rising river carries sufficient to meet the demands of cultivation, if only the water can all be made to enter the canals, and there is a way of avoiding the necessity of allowing a considerable proportion of it to pass the Barrages and find its way out to sea without doing any useful work. The water is there, but the power to utilise it has, hitherto, been wanting. For, before the Weir project was carried out, the top of the Barrage gates in action was at R.L. 14·00. When the gates were fully closed and all leaks caulked as tight as possible, the downstream level would fall below R.L. 10·00. Therefore, as the maximum head allowable was 4 metres, the upstream level had to be lowered to correspond, in order that the head might never exceed the limit. This necessity was felt to be especially irksome at the first rising of the Nile, a time when there is always an excessive demand for water, to meet which a rapid increase of the canal discharges is a thing much to be desired. Some years ago it was pointed out that the ignorance of the cultivators prevented them from appreciating the difficulty of at once increasing the supply as the river rose, and how impatience made them unjust. Mr. Willcocks wrote a paper on "Irrigation in Lower Egypt" for the Institution of Civil Engineers, dated 22nd February 1887, in which he refers to this annoying state of things in the following passage :—

"Tales of the incapacity of the Irrigation Department form, therefore, the ordinary topics of conservation in Lower Egypt from the 15th of July to the 7th August. For it must be remembered, though the Nile is rising, the water level above the Barrages is constant, while all the extra supply coming down the Nile helps to swell the two branches below the Barrages. When both the branches are filled, and the Bar-

# DIAGRAM

## to show the object of the Weirs.


BARRAGE
W. L. with Weirs R.L. 15·50
L.W. L. without Weirs R. L. 13·30
UPSTREAM
R L. 14·00
3·00
Maximum Head on Berrage with Weirs
R. L. 13·30
W. L. with Weirs R. L. 12·50
R.L. 9·50
L. W. L. without Weirs R.L. 9·30
4·00
Maximum Head allowed on Barrage without Weirs
WEIR
Maximum Head on Weir at L.W.L.
3·20
R. L. 15·50
R. L. 12·50
L.W.L. 9·30
6·20
Maximum Total Head possible with Weirs
DOWNSTREAM

rages completely opened, the real rise begins. Not ten Egyptians outside the Public Works Department realise this."

But the yearly-recurring urgency of the demand and the need for more water was undeniable. Evidently then the problem to be solved was to get the power of utilising *all* the water coming from the South in the early stages of the flood, until the canals were carrying such a supply as would satisfy the whole of Lower Egypt. A concession had been made to the demand after 1894 by departing from the hard and fast rule laid down that no higher level than R.L. 14·00 should be allowed above the Barrage till all the gates were fully raised and that level was exceeded as the natural effect of the rising flood. But this concession was not enough, and in fact was only a small instalment of what was possible. The proposal to construct supplementary Weirs afforded the opportunity of giving satisfaction to the demand, so far as the river discharge permitted.

It was first of all decided to limit the maximum head that the Barrage should ever be called upon to sustain, and this limit was finally fixed at 3 metres, which it was considered was a perfectly safe limit after the further strengthening of the foundations which must have resulted from the operations of cement-grouting. Now, experience had shown that, when the upstream level of the Barrage reached R.L. 15·50, the canals carried sufficient volumes to satisfy the needs of the cultivators within a reasonable period. The upstream level was, therefore, fixed at R.L. 15·50. As the Barrage was to hold up 3 metres only, the pool below it must be maintained at R.L. 12·50, which was consequently fixed as the level of the crest of the Weir. As the downstream level, when the Barrage is closed, falls to R.L. 9·30 as a minimum, the Weirs must be made to hold up the difference between R.L. 12·50 and R.L. 9·30, or 3·20 metres. (The accompanying diagram, Plate XVII, shows these projected levels, as well as those which could be obtained without the Weirs to assist.)

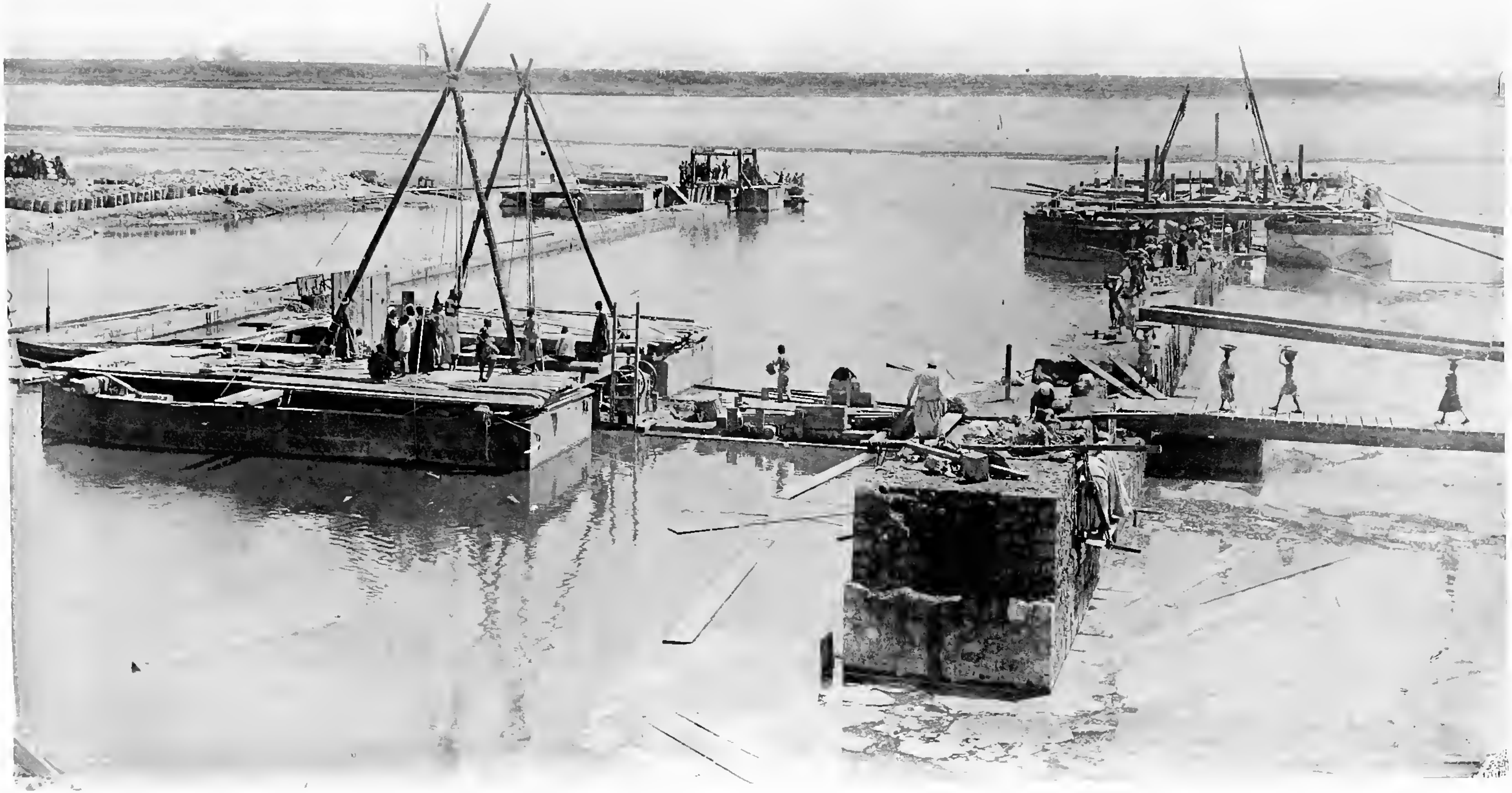
The decision on the foregoing points was not reached all at once, but was the result of the final agreement arrived at by consultations and discussions, such as took place between Sir W. Garstin, as Under Secretary of Public Works, and the author, as Inspector General of Irrigation, in these and all other matters concerning the Barrage, because of the supreme importance of the Work, and the consequent desirability of weighing well and having full sanction for all measures adopted.

So much then, as has been stated, having been decided on, it remained to consider what form the new work should take.

It was calculated that a solid obstruction, of the type of the Indian anicuts, with a fixed crest at R.L. 12·50, would not cause a greater afflux than ten to fifteen centimetres when the river was in high flood. As the Nile banks above the Barrage were already more than sufficiently high to stand this increase on the maximum flood levels, there was no objection to this afflux being produced. And so the solid form of Weir was decided on. The different sections of Indian Weirs were studied, and the Dehree anicut on the Sone was accepted as the most suitable type. In the Dehree anicut, the core and subsidiary walls were formed by sinking wells, a method of construction which has succeeded well in India, but to which there are certain objections, two of the principal being that the rate of progress is uncertain, and that the intervals between the wells are difficult to clear and to fill perfectly, so that there will not improbably be want of uniformity in the depth to which the core wall and other walls are formed, as well as imperfections in the filling, the intervals being the weak points. Especially is it difficult to clear and fill the intervals between wells which, in sinking, have tilted out of the vertical. To meet the objections to wells, Sir Benjamin Baker, who was consulted, recommended constructing the walls below water by forming boxes and filling them with concrete deposited by skips, a trench having first been dredged in the bed of the river to the required depth for the walls. This method had been suggested by alternative cross-sections of different types of Weirs which Sir William Garstin submitted for Sir Benjamin's opinion, one of them showing the walls formed in the usual way by well-sinking, and the other showing the Weir formed in a dredged trench and grouted up into a solid mass with cement.

Sir Benjamin's proposal to construct the Weir wall of successive blocks, formed in boxes by skipped concrete along a dredged trench, was accepted by Sir William as an improvement on the well-sinking method. But experiments made at the Barrage with cement grout had been so successful in forming perfect blocks of masonry below water, that cement-grouted work was in great favour, and was more expeditious, required less supervision and produced more perfect results, all

Plate XVIII



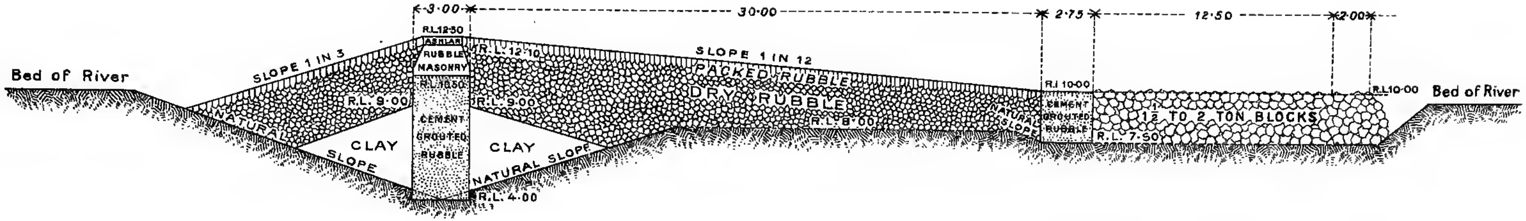
CORE, FOOTING AND FLANK WALLS OF THE DAMIETTA BRANCH WEIR IN COURSE OF CONSTRUCTION, 4th JULY, 1898.

The Core Wall stands in six metres of water, the Footing Wall in $2\frac{1}{2}$, and the Flank Wall in intermediate depths.

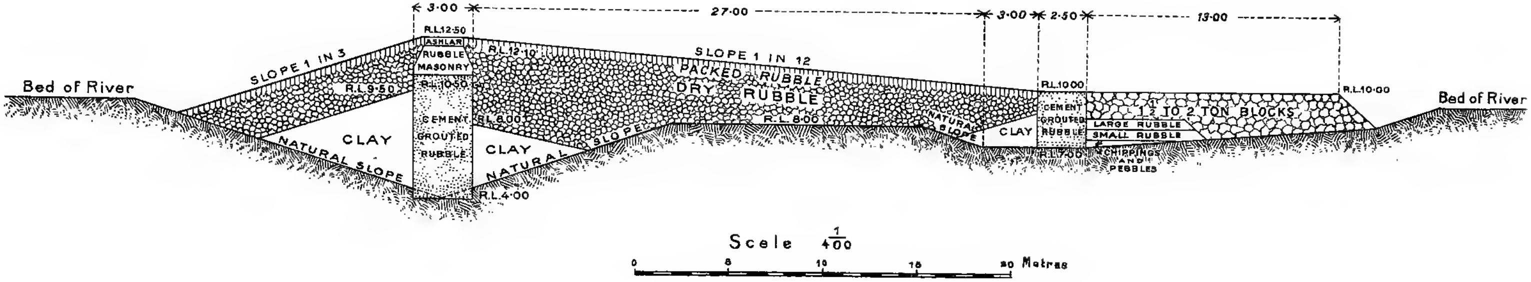
(Photograph by the Author.)

# CROSS SECTIONS OF WEIRS.

## DAMIETTA WEIR, 418 Metres Long.



## ROSETTA WEIR, 500 Metres Long.



important considerations in the case of the Weirs by reason of the conditions under which they had to be constructed. So the cement-grouting system was substituted for concrete-skipping. The cross-section, according to which the Damietta Branch Weir was built, is given in the upper of the two sections on Plate XIX. The Rosetta Branch Weir was constructed according to the lower one. After constructing the former, it was thought better to arrange that the footing wall should hold up water and resist the passage of water below it: but in case of its failing to do this, a filter bed was to be formed downstream of it, so that any water that might find its way under this wall might not carry with it any of the river bed from between the core and footing walls, and cause a subsidence of the rubble pitching between them. This actually took place on a small scale during construction on the Damietta Branch Weir and suggested the modification of the design. However, after one flood level had passed over this Weir, the footing wall held water everywhere.

The process of constructing the Weir was as follows:—

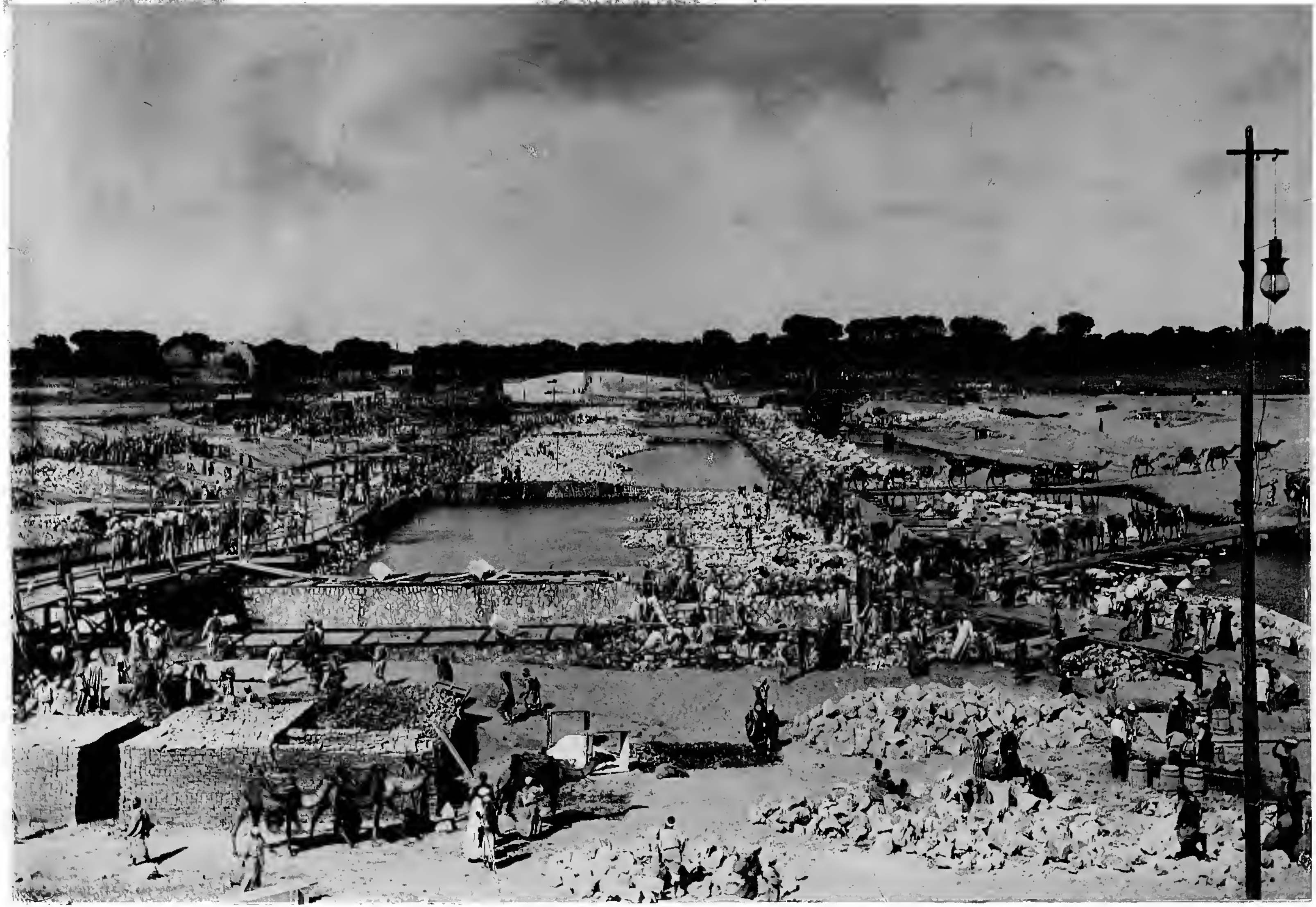
A trench was first dredged out to the correct depths for the bed of the Weir. The core and footing walls were next formed under water to a little above water surface by the cement-grouting method, hereafter to be described. The clay was then put into place against the walls, and the rubble pitching thrown in over it and between the walls. The core wall above water was built to the required height in the ordinary way. At the same time, the heavy downstream blocks of limestone, weighing from 1½ to 2 tons each, were put in place. The surface slope of the Weir was, last of all, built with special stones, about half a metre long, placed on end and packed close.

The chief problem connected with the work was one of transport of a large amount of material in a short time, and there was nothing of a peculiar nature in the method of construction, except as regards the manner of forming the core and footing walls and lock foundations below water. These, as had been decided, were got in by the use of cement-grout. The process of cement-grouting was one day being explained to a lady who visited the works, and she waxed wroth at the idea that there was anything ingenious or original in this method, scornfully remarking that her cook had known of it for many years, and always employed it when he made a pie. The Weirs were forgotten by the rest of the visitors, and the interest was transferred to the pie. A detailed description of the process was demanded. The lady explained that pigeons, or pieces of meat of convenient dimensions, and a certain percentage of bisected eggs and livers to fill interstices, were first of all deposited in a pie-dish, and then covered with a crust and put into the oven. When withdrawn from the oven, hot rich gravy was poured in through a hole in the top of the crust to fill all the spaces between the pieces of meat, until the gravy rose to the edge of the dish. The pie was then set aside to cool, and, when cool, its interior was found to be a solid mass of material, compacted together by the congealed gravy into a monolithic whole. There was no necessity after this for any further explanation on the works, the only difference in the nature of cement-grout and gravy being, that the former sets hard after a certain time when mixed with water, and the latter when it cools. The property that the fluid has of setting hard after a convenient interval is the useful property that each possesses, and the further property that cement has of setting below water is another useful quality, which was taken advantage of in the Weirs.

But, in the case of the Weirs, the box to hold the material was not such a simple vessel as the pie-dish. The blocks, of which the core wall was made up to had to be formed in from 6 to 7½ metres (about 20 to 25 feet) of water, and the sides of the boxes had to be so well constructed that the grout should not escape either where the sides joined the bed of the river (which closed the bottom of the box), or between the joints of the sides and ends. The description of the final form of the boxes and the apparatus employed to put them together, as well as the diagrams, are reproduced from the Irrigation Report of Lower Egypt for 1899, in which Report and in those of the preceding and succeeding years, a full account is given of the construction of the Weirs.

The season's work commenced by getting the plant prepared and the materials collected. As soon as the river had fallen sufficiently towards the end of November, dredging commenced, and the bed of the river was taken out to the cross-section of the river bed. When the dredging was sufficiently advanced for work on the Weir to commence, the water-level at the site of the work was reduced to R.L. 11·50 by regulation on the Barrage. A raft, formed of two large barges kept by timbers at a convenient distance apart for constructing the boxes between them, was moved into position, and a four-sided box, 9 metres

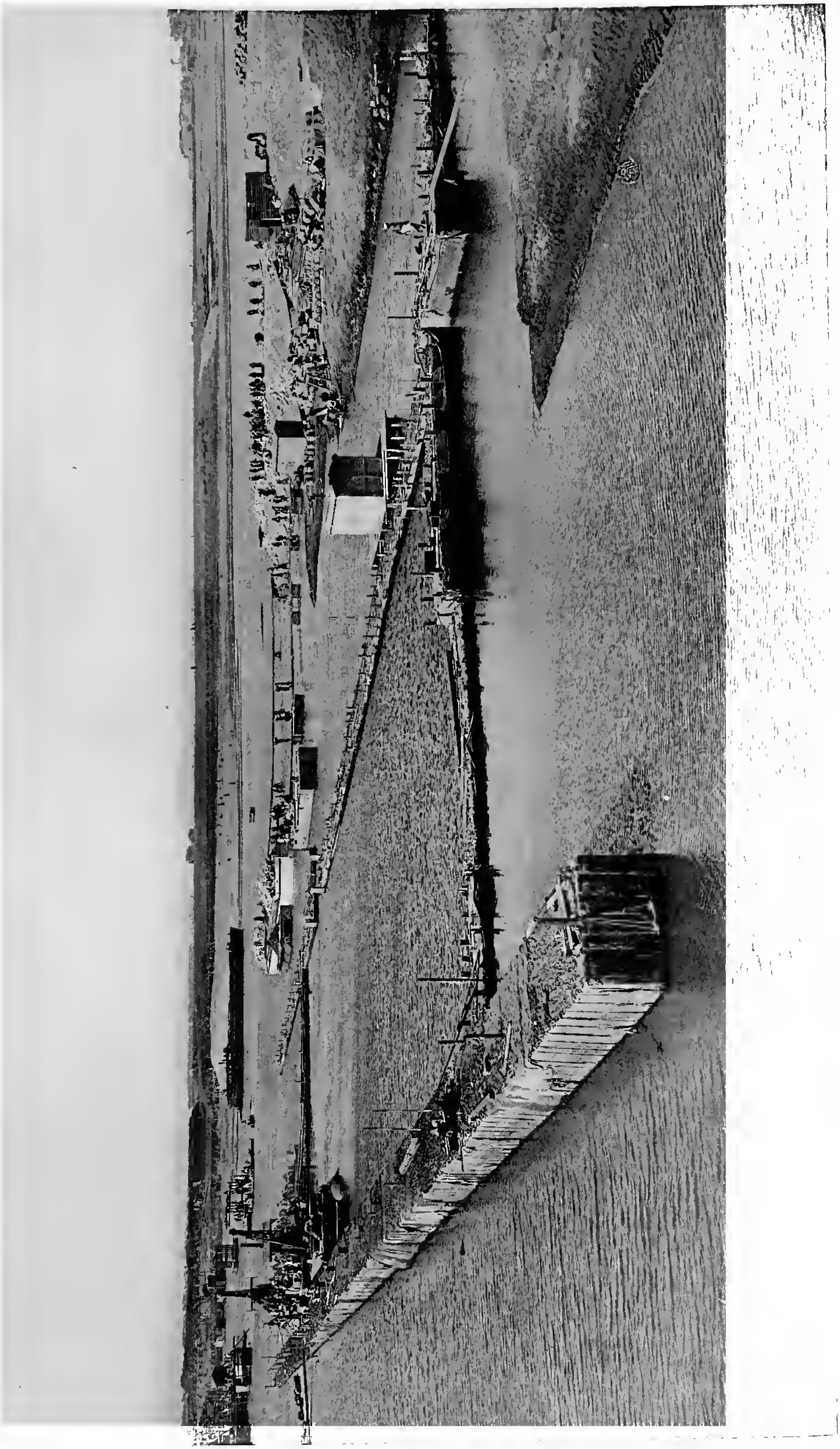
PLATE XX.



DAMIETTA BRANCH WEIR LOOKING WEST, 14th JULY, 1899.

(Photograph by the Author.)

ROSETTA WEIR UNDER CONSTRUCTION.



ROSETTA WEIR LOOKING WEST, 2nd MARCH, 1900.

(Photograph by the Author.)

long, 3 metres broad and 8 metres high, was put together. This box was made as follows (*see* Plate XXIII):—A double tier of horizontal frames was suspended between the barges, the lower frame being supported by chains attached to the upper frame. The upper frame was so hung as to be at water-level, with the lower frame 4 metres below it. The barges having been moored in correct position, the box frames were then got into accurate alignment and fixed there. The sides of the box were then formed of ungrooved sheet piles, 30 centimetres wide, fastened together in sets of five so as to make up a width of 1·50 metres; they were weighted at the bottom end, so that they might tend to float vertically in water, and be, in consequence, the more easily handled. The bottom end was shod with a piece of projecting sheet iron, so as to make a good joint with the river bed, and prevent the escape of the grout. When the sides of the box had been formed, the whole interior surface of it was lined with sacking, overlapping at the angles and at the bed junction. The sacking was kept in place and protected from being torn by the rubble, when filling was going on, by thin planks nailed about a metre apart against it from water surface to bed. Divers were constantly at work during these operations. Four perforated pipes were then fixed along the axis of the box at equal distances, and the box was filled with rubble and concrete metal (20 per cent) and pebbles (15 per cent), thrown in from above, up to slightly above water-level. Unperforated pipes were then inserted into two alternate perforated pipes, reaching nearly to the bottom of the box: on the top end of these pipes were screwed funnels, and over the funnels were fixed coarse wire sieves to catch the pieces of paper of the cement barrels and other foreign substances that might get mixed with the cement-grout and clog the perforations if they were to be carried down the pipes. In the other two pipes floats, so weighted as to sink in water and float in cement-grout, were suspended, so that the rise of the grout might be watched. The object of grouting into an unperforated inner pipe was to deliver an unbroken column of grout, at first at the bottom of the box, and, afterwards, just below the surface of the sea of ascending grout. If grout had been poured directly into the perforated pipe, each bucket of grout would have had to fall through water. The inner pipes were changed over from time to time to the alternate perforated pipes, and gradually shortened as the grout rose higher. To lessen the danger of leaks at the bottom of the box from the pressure of too great a head of liquid grout, (which being twice as heavy as water exercises a pressure in water equal to the pressure exerted by a head of water in air,) it was generally arranged that a depth of one metre should be grouted over-night, and be left till the next morning to set, so as to form a solid bottom to the box, on which the rest of the grout would be supported.

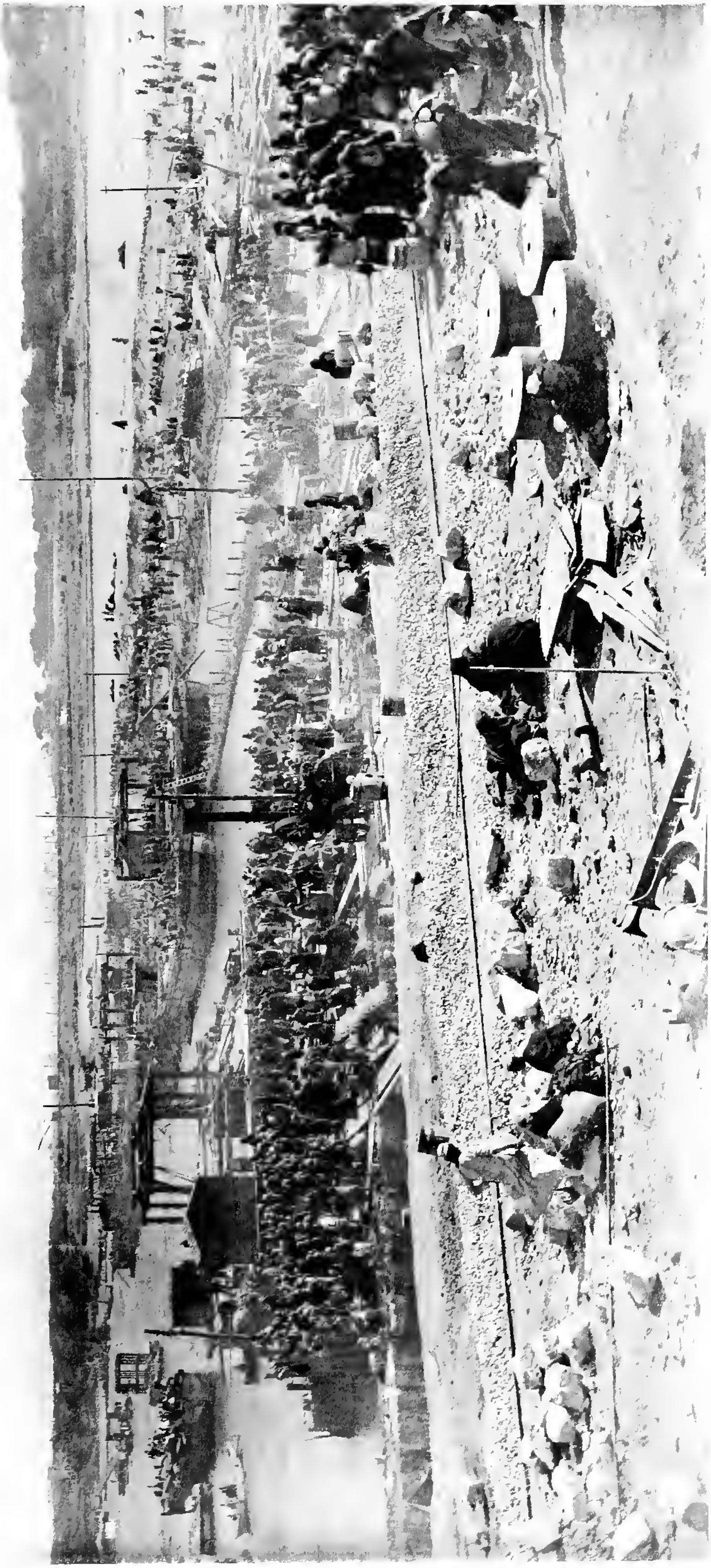
The grouting was continued next day until the grout rose slightly above the water surface; the scum was cleared away, and stones put by hand into all the spaces where there was an excess of cement grout. The block was then left for the night, and next morning was found to have set hard enough for the box, in which it was formed, to be cast loose and moved forward.

The second and subsequent boxes were made as three-sided boxes, the last grouted block forming the fourth side, and being clasped by the side beams of the horizontal frames.

A box and its contained block took from three to four days to make, so that, when the four rafts were at work, the average rate of progress was about 10 metres of core-wall or lock-wall a day. Each block contained from 160 to 170 cubic metres of masonry, and was about 9 metres long by 3 broad and 6 high. At the commencement of the season, the blocks were 7½ metres high, decreasing to 6 metres as the water fell.

The cement-grout was mixed by hand in iron troughs by ordinary labourers, gangs of Soudanese Blacks being the best mixers. The consistency of the grout varied from thin to thick, the proportion of water depending on the judgment of the mixers. When first using cement-grout to strengthen the Barrage foundations, attempts were made to measure the amount of water; but, in consequence of the peculiar nature of the workmen, the measuring was never properly done; and so it was decided to give up the measures, and to control the consistency by observing what was brought in buckets to the grouting pipes. Experiments and experience on the work itself seemed to show that, whether thin or thick, the cement-grout set satisfactorily and gave the desired result. Possibly the grout, in consequence of its high specific gravity, gets rid of excess of water when it is in a liquid mass and free to do so. Whatever the explanation, it appeared to be unnecessary to be particular about the proportion of water in the grout when used as in the work under description. But it is necessary

ROSETTA WEIR UNDER CONSTRUCTION.

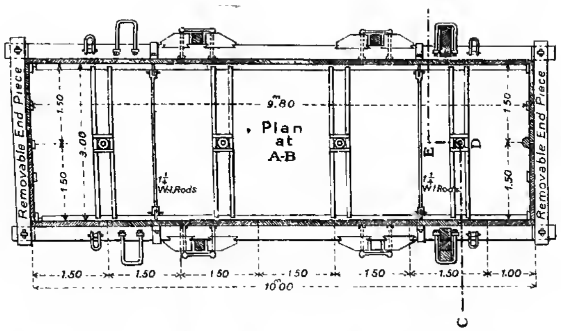


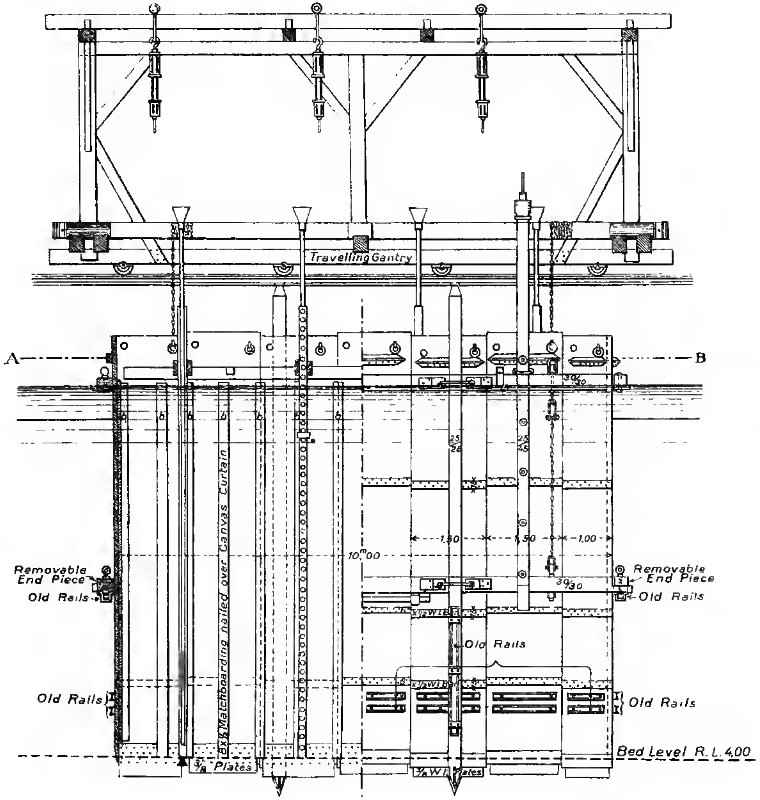
ROSETTA WEIR LOOKING EAST, 2nd MARCH, 1900, DURING THE GROUTING OF THE LOCK FLOOR.

(Photograph by the Author.)

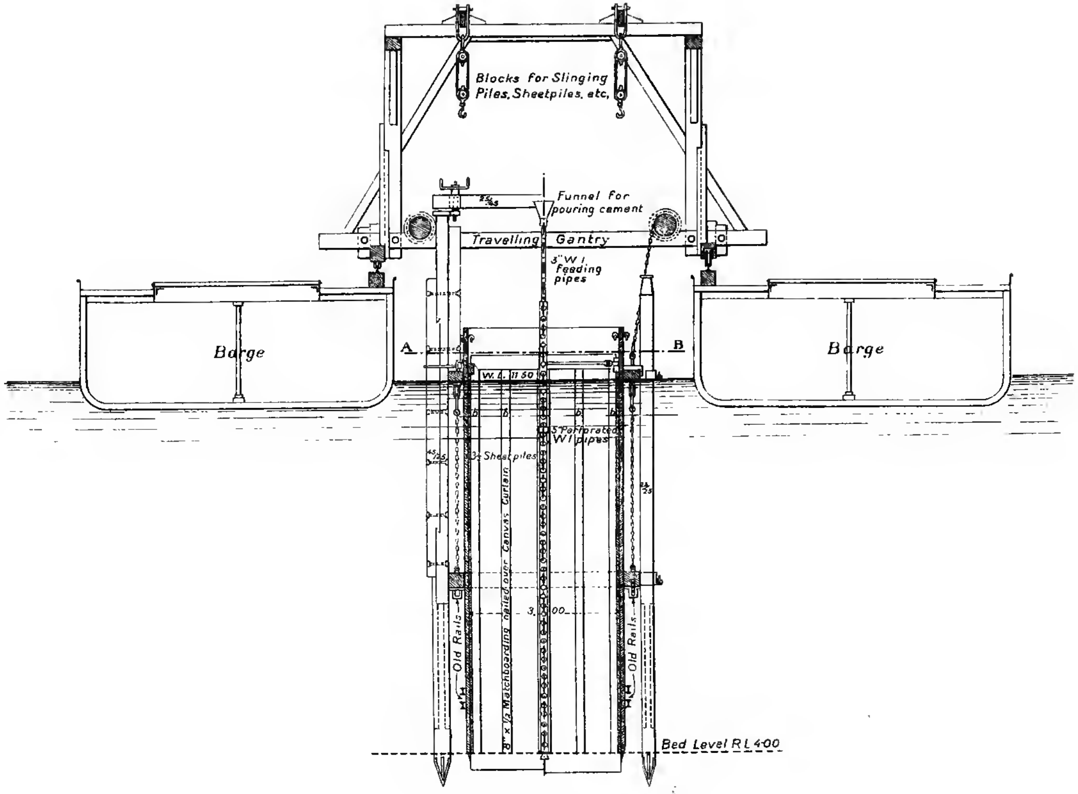
# BOX AND FLOATING GANTRY
## Used on New Weirs
## for grouting Sub-aqueous Walls

Scale cm 100 50 0 1 2 3 4 5 Metres





Half Section | Half Elevation



Section C.D.E.F.

to be careful to get a cement that will behave satisfactorily under such severe conditions, and this appears from experiments made with many kinds of cement not to be a difficulty.

The diagram of the apparatus designed by Mr. Mason, and used in 1900 to form the footing wall of the Rosetta Branch Weir, is also given on Plate XXIV.

The lock foundations were got in entirely by grouting, Mr. F.R. Stent with Mr. J.H. Grieve to assist him being entrusted with the work, which they carried out with conspicuous success. As I believe this system has never been applied to such an operation before, it may be useful to describe the manner of doing it (*see* Plate XXV.)

The foundation bed was dredged out all over to R.L. 5·50, and the water-level reduced by regulation on the Barrage to R. L. 10·00. Two parallel walls, bounding all the lock area on either side, were then formed by the same system as that adopted for the formation of the core-wall. The rectangle of which these walls formed the sides (100 metres long by 17 metres broad in the clear between the walls) was then closed at the two ends by sheet piles supported by horizontal beams, which were kept in place by piles driven a short distance into the bed of the river and tied at their tops to the side walls already made. A staging was then constructed across the enclosed space from side wall to side wall, the perforated pipes having been first fixed in place about 3¼ metres apart all over the area. The pipes were fitted with iron brackets to make them serve as upright supports for the staging. Two metres depth of rubble, concrete metal and pebbles were then thrown in to form the floor foundation. At about one metre distance from the two ends a second interior cross wall of sheet piling was arranged with the lower ends below the level to which the two-metre layer of rubble would come. All the sheet piling was lined on the inside with sacking to prevent the escape of cement-grout between the joints, in the same way as in the boxes.

When the two-metre depth of floor material had been deposited, grouting commenced at one end of the lock and continued till the other end was reached. The end walls were then filled and grouted. The enclosed space was then pumped out in half a day, and the grouting was found to have formed a perfect floor without the sign of a spring in it. The rest of the lock floor and walls was built in the dry in the ordinary manner.

As the grouting was executed under water and was not continued, as in the boxes, until the grout rose above water surface, arrangements had to be made for ascertaining to what level the grout had risen. A simple arrangement revealed this. The grout was poured into one of a pair of pipes, and, in the other adjacent pipe where grouting was not going on, a float was suspended so weighted that it would sink in water and float in cement-grout, the specific gravity of the latter being double that of the former. The string to which the float was attached was passed over a pulley wheel, and the other end of the string weighted sufficiently to keep the string taut.

The cost of pumping out the lock space was under £E.50, and this was the only expenditure in pumping incurred in getting in the foundations of the weir and lock on either Branch.

By this method a perfectly sound floor is obtained, as no troublesome springs create defects by forming a way under or through the masonry while under construction. When the cement has set, the springs are all effectually shut out and helpless, and the enclosed water can be pumped out without any fear or difficulty.

Sir William Garstin's final decision as to the form to be adopted for the Weirs was given early in February 1898. The original intention was only to collect material and plant the first season. But Sir William directed that two or three blocks should be formed in the river bed itself in order to find out the best method of working. It was decided to make the experimental blocks in the line of the core wall, so that, if successful, the work done would be so much to the good. A sand dredger was therefore set to work in the Damietta Branch on the 15th March 1898. By the 15th May a box had been formed in place and filled with stone, and His Excellency Mohamed Fakhry Pasha, Minister of Public Works, emptied the first bucket of grout into the distributing pipes the same day.

At the start work went badly, the cement-grout escaping freely from the first box at every joint, as there was no lining of sacking used. The second box was so lined, but was not rigidly held to the first block formed, and also leaked badly. In these two boxes 2,362 barrels of cement went to make 327 cubic metres of masonry! The next three boxes gave better results, but still not good enough; and it was thought that we might have to resort to the skipping method after all. But every box saw some improvement introduced, until at last the

sixth box proved a success, 3·60 barrels to the cubic metre being used. So skipping lost favour again.

The experiment of making two or three blocks was pushed to such an extent that, by the end of July, when work stopped, thirty-three blocks had been formed by grouting and nine by skipping, thus completing all the sub-aqueous work of 80 metres length of the Weir. There was, besides, constructed the terminal flight of steps and the wing joining the core and footing walls, as well as the revetment of the slopes on the west flank of the Weir. Mr. Allan Joseph, the then Director of the Barrage, started the work of the Weirs, but retired from Government Service before the first season's work came to an end. Before the commencement of the second season, Mr. O. G. Brooke was appointed Director of the Barrage, and, as such, was charged with the construction of the Weirs.

The first season's work was most valuable, and gave the knowledge that was required for adequate preparations to be made for the next season's work. Without it the Damietta Weir would probably not have been carried right across the river the following season. As it was, the second season's work completed this weir up to R.L. 11·50, with the exception of 200 metres carried up to R.L. 11·00 only: the lock also was built up to R.L. 13·30. The whole length of the Weir crest between the lock and the foot of the West flight of steps is 418 metres. The season's work began with dredging on the 20th November 1898, but it was not till February that the first block of the season was formed. As in the year before, work stopped on 31st July, when the programme for the season was completed, but without an hour to spare.

The Weir crest was left low with the object of watching the effect of a flood over it before it was raised to full height, and also to facilitate later on the diversion of the water of the Rosetta Branch into the Damietta, so that work might begin the sooner on the other Weir in the following season.

The programme for 1900 was a formidable one. Besides the completion of the Damietta Weir Lock, and further raising of the Weir itself, it was decided to complete the construction of the Rosetta Weir to one metre below finished crest level, and to build its lock to at least three metres above floor. The length of the Weir between the lock and the foot of the east flight of steps is 500 metres.

The low levels of the 1899 Nile flood allowed the early execution of earthwork by hand at the two ends of the Weir, and the river had fallen sufficiently by 1st November for dredging to begin. Two blocks had been formed by the end of the year 1899. Before the end of July 1900 the season's programme had been more than completed. The 500 metres of Weir had been built to the height proposed (and even more, as 200 metres length of it was carried higher), the lock was completely finished and gates hung, and the flight of steps and flanking revetment slopes built. Without much further effort, both Weirs with their locks might have been completed throughout, and no work have been left for a fourth season. As it was, little was left to be done, and that little was completed with ease the following season as soon as the river levels allowed the work to be got at. The last coping stone of the core wall of the Rosetta Branch Weir was laid on 16th May 1901.

During the 1900 season 172,000 cubic metres of building material of different sorts (as measured in the work) had to be transported from store or stacking ground to the Rosetta Branch Weir alone. The traffic management of seven contractors' locomotives and of about a hundred and fifty trucks on which depended the rapid transport of this large quantity of materials in a limited time, was, for the most part, put into the hands of Mr. E. Mason, with good results. The late Mr. J. G. West distinguished himself by his successful management of his share of the grouting operations by which the core wall was formed. Mr. H. Boyes was another active member of the staff that built the Weirs.

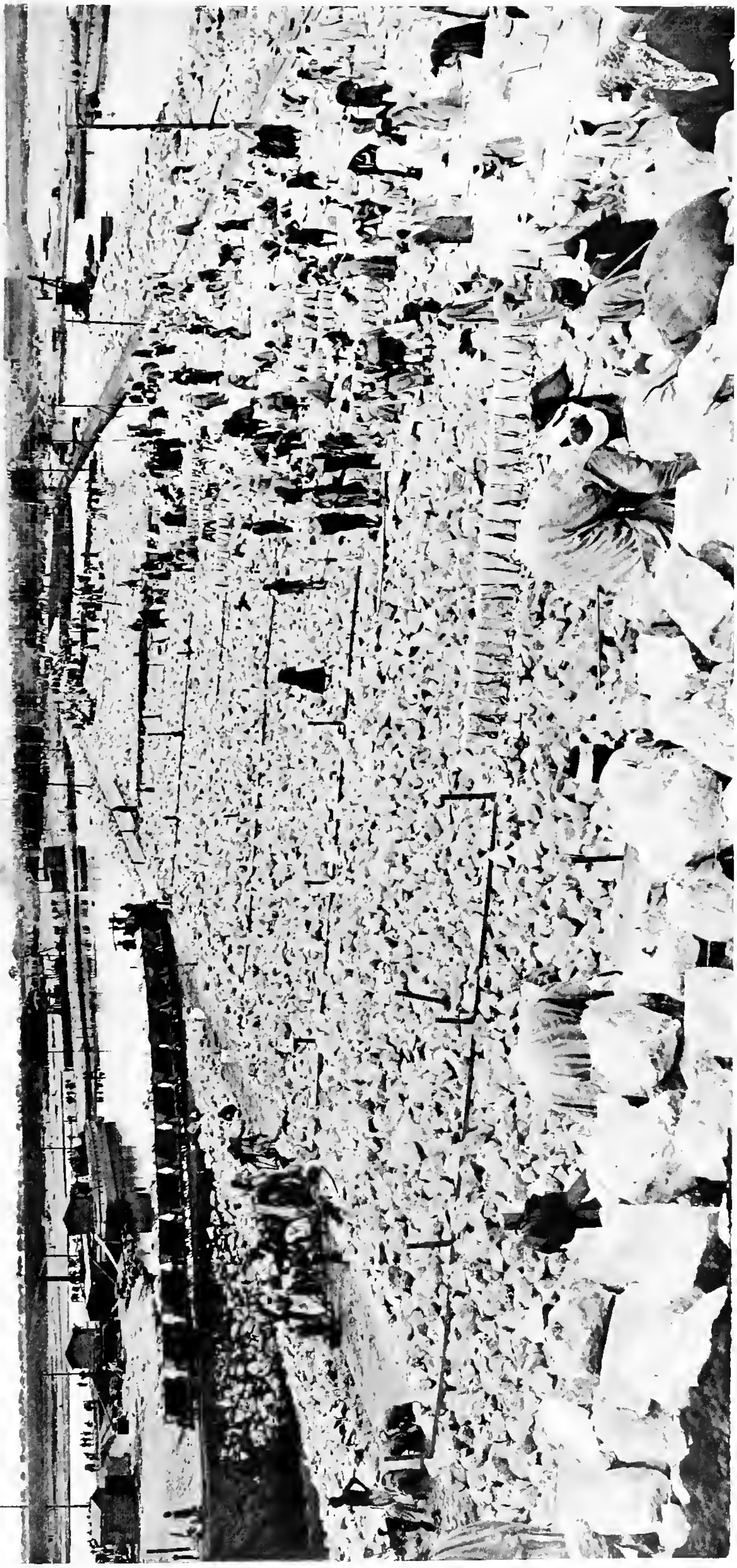
The total cost of the two Weirs, and work in connection with them was £E.434,000, so that there was a saving on the allotment of £E.96,000. The work was carried out departmentally under the direction of the Government officers whose names have been mentioned in this Chapter.

The total quantities of work done were:—

| | Cubic metres. |
|---|---|
| Dredging... ... ... ... ... ... ... ... ... ... ... ... ... | 398,802 |
| Earthwork by hand ... ... ... ... ... ... ... ... ... ... | 266,706 |
| Grouted masonry ... ... ... ... ... ... ... ... ... ... ... | 43,570 |
| Skipped concrete ... ... ... ... ... ... ... ... ... ... ... | 1,660 |
| Rubble masonry in ordinary mortar... ... ... ... ... ... ... | 9,090 |
| Rubble masonry in cement and sand... ... ... ... ... ... ... | 7,093 |

PLATE XXVI.

ROSETTA BRANCH WEIR.



PHOTOGRAPHED FROM EAST END ON 4th JUNE, 1900, BY THE AUTHOR.

| | Cubic metres. |
|---|---|
| Brick masonry | 10,039 |
| Ashlar masonry | 2,662 |
| Dry rubble masonry | 170,916 |
| Heavy talus blocks | 27,205 |
| Clay on sides of walls | 55,081 |

Ironwork for two 12-metre locks.
Iron additions to 122 Barrage gates: about 183 tons.
Two winches for Barrage gates.
Three bridges over canals for trolley lines.

For the sake of recording it, the exact levels of the Weir crests are here given. The crest of the weir on the Rosetta Branch is at R.L. 12·56 throughout. The crest of the weir on the Damietta Branch is generally at R.L. 12·45, but its west extremity rises to R.L. 12·46, and its east extremity to R.L. 12·47.

It was pointed out in a previous chapter that the level of the top of the gates, with which the Barrage was fitted during the restoration work of 1888 to 1890, was R.L. 14·00 when the gates were fully down. It has also been explained at the beginning of this chapter that the Barrage in future will be called upon, as the flood commences to arrive, to hold up to R.L. 15·50. It was, therefore, necessary to provide means for closing the one and a half metres additional height of waterway, and the simplest way of doing this was to make the requisite addition to the upper gates. This addition was made in 1900, so that all the upper gates are now four metres in height. It was feared that, with this increase of gate area, it might be impossible to raise all the Barrage gates in a short enough space of time, should there be a rapid rise of the river. But there cannot well be an unexpected rise, now that we get daily readings of river gauges from as far south as Khartoum and also from points above Khartoum on the White and Blue Niles. Still, to meet this objection, it was decided to add a third winch to each Barrage. The cost of making the additions to the gates and also of the two winches, amounting to £E.13,157, is included in the sum given above as representing the total cost of the Weirs, as it was part of the project for which the Caisse de la Dette made their grant of £E.530,000.

The Weirs, it has been explained, have been constructed with a two-fold object, namely, to lighten the duties of the Barrage by relieving it of part of the maximum pressure it was expected to support, and to make it possible to utilise to the full the first rise of the flood, in July and August. By the power that they give of raising the upstream level of the Barrage a metre and a half to two metres higher than it could be raised without them, the discharging power of the canals in summer is increased (if water is available) by adding to their depth, whereby the costly process of widening them will be avoided whensoever the necessity arises for increasing their carrying capacities, which will be when reservoirs in Upper Egypt add sufficient to the available summer supply. Already an economy in dredging and silt clearances has resulted. When the Barrage was restored and rendered capable of holding up a head of four metres, the amount of silt clearances necessary to make the canals carry their summer supply was reduced to such an extent that the abolition of the Corvée and the substitution of paid labour to do its work became a possibility. The power of holding up to still higher levels, which is given us by the Weirs, will make a further economy in silt clearances possible, to what extent is not yet known. But in 1901 a large economy has been effected in the dredging bill of the Rayyah Menufiyah; and the level, to which the Ismailiyah Canal at its head has to be dredged, has been raised twenty centimetres, and it is found that it can be safely raised another twenty-five centimetres.

If the Weirs have not already paid back in value of results all the money spent upon them, they very soon will have done so. The work that they have already actually done is set forth below:—

(1) The maximum head on the Barrage was reduced from 4 metres to 3·85 metres in 1900 and to 3 metres in 1901.

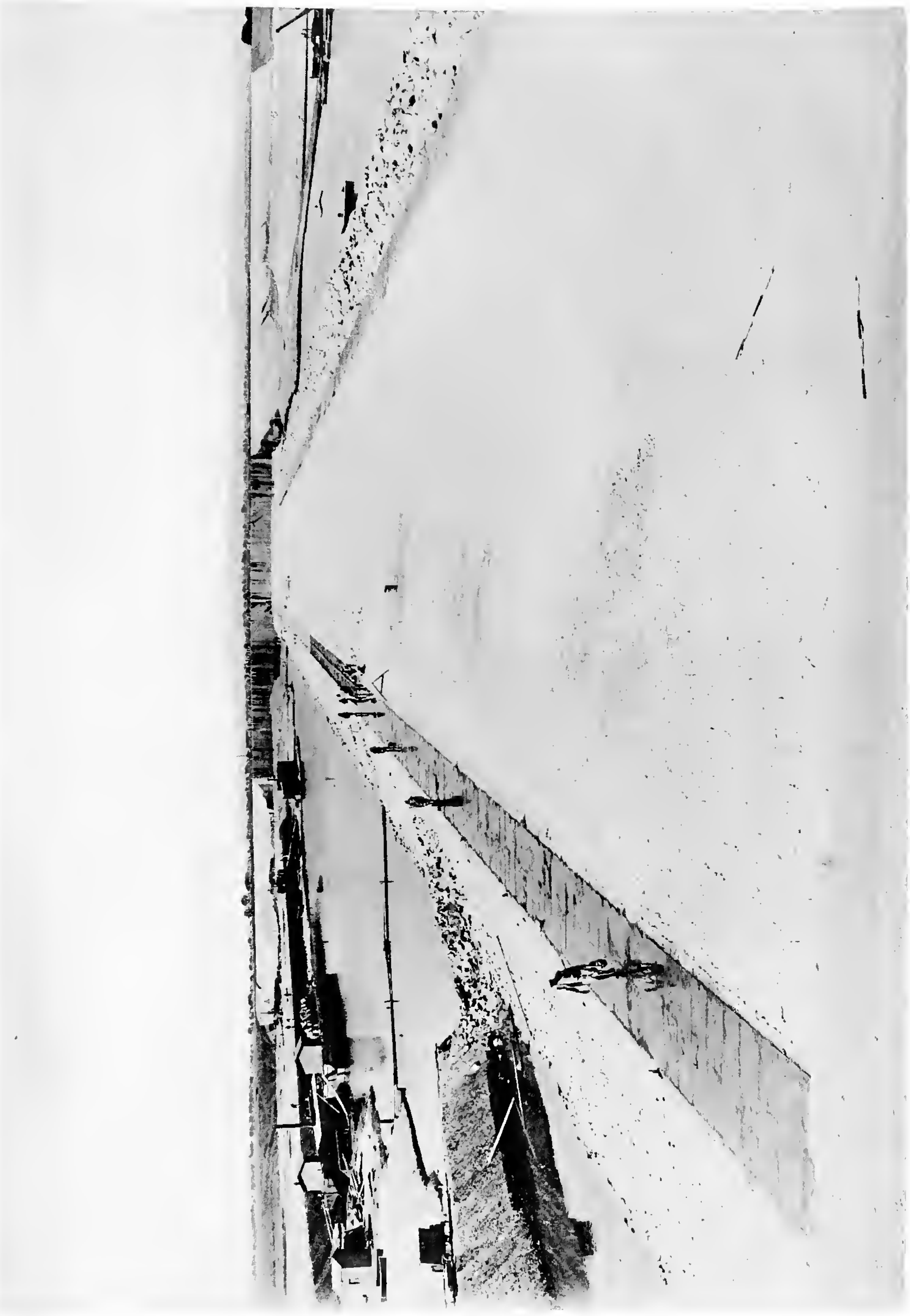
(2) Not only was the Barrage relieved to the extent given, but a maximum combined head, on Barrage and Weir, of 5·95 metres was held up in 1900 and of 6 metres in 1901, giving a gain of 1·95 metres in the former year, and of 2 metres in the latter over the level upstream of the Barrage which would have been permissible, had the Weir not been in action.

(3) The expenditure on dredging in the Rayyah Menufiyah and Canal Ismailiyah has been sensibly reduced in 1901.

(4) The upstream level of the Barrage in July 1900 was raised to R.L. 15·50 several weeks earlier than it could have been without the help of the Weirs, and so the canal discharges were increased to the

Plate XXVII.

## ROSETTA BRANCH WEIR.



WORK AT THE END OF THE SEASON. PHOTOGRAPHED ON 22nd JULY, 1900, BY THE AUTHOR.

amount required to allow of the maize crop being got into the ground during the favourable season for sowing it, so that a good crop was obtained.

The Weirs are still too new an addition to our means of controlling the water supply for all the benefits obtainable from them to be yet recognised. They are, we know, capable of doing all that they were designed to do, for they have been subjected in 1901 to the maximum head that they can be called upon to bear and they have shown no signs of imperfection anywhere under the test.

# CHAPTER VI.

## WORK DONE BY THE BARRAGE.

THE whole duty of the Barrage is to raise water to the mouths of Lower Egypt that the lands may drink and be satisfied. The varying efficiency with which it has performed this duty at the different periods of its existence can best be judged by a study of the gauge registers which show what effect its action has had upon the river levels in the Cairo reach, from which all the Delta canals draw off their supplies of water.

To enable a comparison to be made between the effect produced by the Barrage before and after its restoration, it will be useful to give an account of the manner in which the Barrages were regulated previous to 1884. This account is taken from "Egyptian Irrigation" (Willcocks).

"When the Nile gauge stood at R.L. 12·50 metres, which generally happened in March, the Rosetta Barrage gates and piles were quickly lowered to their full extent, beginning at opening No. 61 (east end) and closing at No. 1 (west end). The consequence was a rapid current through the last openings just before they were closed. It was on one of these occasions that the ten openings from No. 5 to No. 14 were injured, according to the Report of the Egyptian foreman on the work. The Government Report states that they were injured during the floods of 1867 owing to contracted waterway. As soon as the gates and piles reached the gratings, they could descend no further, and the work of regulation was at an end for that year. The upstream gauge rose to 13 metres, while the down stream gauge fell to 11·25 metres; so that, with a difference in water surface of 1·75 metres, there was a gain in water level of only ·50 metre. This was due to the fact that the Damietta Barrage was open. Of the water which escaped through the Rosetta Barrage, practically the whole found its way through the iron gratings. These gratings, with a head of 1·75 metres, were capable of discharging 240 cubic metres per second. The river kept falling through April, May and June, and during the whole of this time the Damietta Barrage was open, as well as the gratings of the Rosetta Barrage. There was not sufficient water in the Nile to allow of a head of 1·75 metres on the latter, and it fell to 1 metre. Towards the end of June the up and down stream gauges roughly indicated 12 metres and 11 metres respectively. If the Rosetta Barrage had failed in June, the loss of head in the Delta canals would have been ·35 metre. When the Nile began to rise in July, and the upstream gauge read 13 metres, the gates were raised as quickly as possible, the river fell to 12·50 metres, and was allowed to recover as the flood rose. This it generally did in six or eight days."

Thus we find that, previous to 1884, the maximum head held up by the Rosetta Barrage was 1·75 metres, decreasing to 1 metre at the time of lowest Nile, and the water level maintained above the Barrage was R.L. 13·00, decreasing to R.L. 12·00 in June. The Damietta Barrage was always open and held up nothing.

From 1884 to 1886 inclusive Mr. Willcocks was in charge of the Barrage. In 1884, in consequence of additions to the rubble talus and improvements made in the closing arrangements of both openings and gratings, the Rosetta Barrage was made to support a maximum head of 2·21 metres, and to maintain an upstream water level of R.L. 13·00, almost throughout the period of Low Nile. The Damietta Barrage held up a maximum head of 0·95 metre.

From 1885 to 1890 inclusive the upstream summer level was kept, with but slight variations, at R.L. 13·00, the maximum head on the Rosetta Barrage varying from 3·00 metres in 1885 to 3·43 metres in 1890. On the Damietta Barrage the maximum head varied during this period from 1·76 metres in 1885 to 3·26 metres in 1890.

Between 1890—the year in which the Barrage restoration was completed—and 1898, the levels maintained above the Barrage varied from R.L. 13·50 and R.L. 13·80 in April and May to R.L. 14·00 in July, the maxima held up at any time having been 4·07 metres on the Rosetta Barrage and 3·72 on the Damietta.

In 1898 the previous record was beaten, the maximum heads having been on the Rosetta Barrage 4·35 metres, and on the Damietta 3·82. The Barrage itself will never be called upon to support these heads again, as the future maximum is limited to 3 metres. But, in combination with the lately constructed Weirs, the total head permissible will be a full 6 metres, the maximum ever contemplated in any project for the Barrage; and that project was the original one that M. Mougel submitted to the Conseil des Ponts et Chaussées in 1843.

To show the results in a convenient form for comparison, the following table is given :—

| PERIOD. | MAXIMUM HEAD | | Actual upstream levels in June. | Maximum upstream level possible by regulation with Barrage gates down, given sufficient supply in the river. | REMARKS. |
|---|---|---|---|---|---|
| | Rosetta Barrage. | Damietta Barrage. | | | |
| | | | R.L. | R.L. | |
| Previous to 1884. | 1·76 | Nil. | 12·00 | 12·00 | Work condemned as useless. |
| 1884–1886 ... | 3·05 | 1·76 | 12·90 to 13·00 | 13·00 | Mr. Willcocks's measures effective. |
| 1887–1890 ... | 3·43 | 3·26 | 12·90 to 13·00 | 13·00 | Restoration going on. |
| 1891–1894 ... | 4·07 | 3·72 | 13·22 to 13·75 | 14·00 | Mr. Foster's clay additions to Damietta Barrage. |
| 1895–1900 ... | 4·35 | 3·82 | 13·50 to 14·00 | 14·00 | Foundations cement-grouted and Weirs being constructed. |
| Future ... ... | 3·00 | 3·00 | 13·50 to 14·00 | 15·50 | Weirs completed and in operation. |

In the summer of 1892 the upstream level fell to R. L. 13·22, in 1898 to R. L. 13·50 and in 1900 to 12·92. This was not because the Barrage could not hold up more, but because there was so small a discharge in the river that the draw of the canals, taking off from above the Barrage, kept the water surface upstream of it low. In these three summers the Barrage gates were carefully caulked with rags to stop leakage, and every drop of water in the river was turned into the canals. The Barrage could do no more.

The minimum level of 1900 was higher than it would have been, had all the six canals, taking off from above the Barrage, been left fully open, as was the practice in former years. With all the canal heads fully open, the Barrage upstream level would have fallen to some point between R. L. 12·92 and R. L. 12·40, approximately to 12·60; and, therefore, this last is the figure that should be used when comparing the summer supply of 1900 with those of 1892 and 1898. The summer levels of 1900, as shown by the gauge readings at Aswan, were the lowest on record. The discharge of the river was so small that a strictly just distribution of the scanty supply was imperative. The Heads of the Rayyah Menufiyah, Canal Basusiyah and Canal Sharkawiyah were left fully open, while the Rayyah Tewfiki, the Rayyah Beherah and Canal Ismailiyah were regulated upon to make the discharges of each of the six canals proportional to the areas commanded by them.

During the very low flood of 1899 the Barrage was regulated on for the first time during a flood season, and the lowness of the flood had, in consequence, no serious effects in Lower Egypt. Throughout the following summer months of the lowest of low Niles, the Barrage gates were tightly caulked with rags and the whole river diverted into the six main Delta Canals. Probably during no previous period of twelve months has the Barrage done so much to promote the prosperity of Egypt, and to justify all the expenditure that has been incurred upon it; though that has been justified over and over again. Not only was the cotton crop safely brought through months of scarcity, but, in consequence of the advanced state of the construction of the Weirs, it was possible to give so abundant a supply when the flood water began to arrive, that the maize crop (the sowing of which had been forbidden until then) was got in so quickly and under such favourable conditions that it proved to be above the average. The cotton crop would have been a considerably heavier one than is given in the statement further on, had it not been for unfavourable weather prevailing in September, whereby the plant, that up till then had a most flourishing aspect, was seriously damaged and its yield much diminished.

Of the benefits that have followed as a consequence of the work done to the Barrage from 1887 to 1901, the figures of the successive cotton crops perhaps speak most eloquently and convincingly. These figures are obtainable for the last eighty years, that is, since the commencement of cotton cultivation in Egypt. Those for the years succeeding 1880, have been obtained from the Alexandria General Produce Association and may be relied upon to be as accurate as possible. The figures for the years previous to 1881 were given in a list published some years ago by the Egyptian Gazette.

The first crop on the record is that of 1820, which produced 944 kantars: the next year the figure had increased to 35,108 kantars. (A kantar is about a hundred-weight). From 1822 to 1848 the yield varied from 120,000 to 345,000 kantars.

In 1849 the yield was 364,816 kantars
1850 „ „ „ 384,439 „
1851 „ „ „ 670,129 „

The high figure of 1851 was not maintained, but the yield never fell again to what it had been before 1851. From 1852 to 1859 the year's yield varied from 480,000 to 540,000 kantars. The few years following 1860 were a succession of record-beating years:—

In 1860 the yield was 590,200 kantars
1861 „ „ „ 721,052 „
1862 „ „ „ 1,181,888 „
1863 „ „ „ 1,718,791 „
1864 „ „ „ 2,001,169 „

The Barrage was declared to be finished in 1861, and it would seem from the foregoing figures to have had a great effect. But the increase in the cotton cultivation from 1861 to 1864 was due to the high prices obtained for Egyptian cotton during the American Civil War, which lasted from April 1861 to May 1865. It was this which gave such impulse to cotton growing in Egypt that the crop of 1864 produced almost four times that of any crop previous to 1860. But this increase was not kept up to its full extent after the war, as the figure fell from 1865 to 1869 to an average of about 1,300,000 kantars. It rose again, however, to between 2,000,000 and 3,186,000 kantars from 1870 to 1883.

Previous to 1884 the highest figure reached had been that of 1879, viz, 3,186,000. The figures for the years succeeding 1883 are as follows:—

| YEAR | Kantars of Cotton | Nature of River Supply in Summer | YEAR | Kantars of Cotton | Nature of River Supply in Summer |
|---|---|---|---|---|---|
| 1884 | 3,629,000 | Good | 1893 | 5,033,235 | Good |
| 1885 | 2,871,500 | Bad | 1894 | 4,619,233 | Mean |
| 1886 | 2,872,426 | Mean | 1895 | 5,256,128 | Good |
| 1887 | 2,996,485 | Mean | 1896 | 5,879,479 | Good |
| 1888 | 2,722,954 | Bad (very late flood) | 1897 | 6,566,487 | Good |
| 1889 | 3,237,558 | Very bad | 1898 | 5,583,306 | Bad |
| 1890 | 4,159,405 | Bad | 1899 | 6,435,735 | Good |
| 1891 | 4,765,341 | Mean | 1900 | 5,435,480 | Very bad |
| 1892 | 5,220,510 | Bad | 1901 | 6,250,000 estimated | Bad |

The cotton crop must naturally depend on the water supply, but the yield of the crop does not vary in direct proportion with the summer discharges of the river; nor, as I have known to be maintained, in inverse proportion. A limitation of the water supplied to the crop is advantageous, as the fellah is apt to over-water if his supply is unlimited, though he is credited by many with an infallible genius for all kinds of farming operations, such as no other child of the soil in any other country displays. There are some sceptics, not without power of observation, who decline to accept this estimate of the fellah's pre-eminence, but are rather inclined to explain why the facts are otherwise, pointing out that Nature does all the work and contriving, and the fellah sits still and looks on. This being fairly true of the ancient system of basin irrigation on which the fellah's ancestors were brought up, the genius of farming, where nature is not so obliging and with crops that require attention and skill, can scarcely have become innate by the process of evolution operating over a period of less than eighty years. Mr. Willcocks adorns the title page of his "Egyptian Irrigation" with a passage from Shakespeare, which reveals the poet's accurate conception of farming operations in the Egypt of his day.

"The higher Nilus swells
The more it promises: as it ebbs, the seedsman
Upon the slime and ooze scatters his grain,
And shortly comes to harvest."

There is a primitive simplicity about these farming operations, which has nothing in common with the warring against difficulties and keen competition whereby higher types and pre-eminence are usually evolved.

Mr. Willcocks apparently has no faith in the genius of the fellah being able to secure a permanent victory in agricultural struggles with Nature, for he seems to suggest that there must be a reversion to the ancient system of irrigation. Immediately below the Shakespearean passage on his title page is another quotation under the heading "Modern System of Irrigation," and it is this:—*Naturam furcâ expellas, tamen usque recurrit.* But a good deal depends upon the wielder of the pitchfork: unskilful or enfeebled handling of the agricultural weapon would, no doubt, help to show that the proverb stated an inevitable sequence: but so long as the pitchfork be wielded with the same skill and vigour as was found sufficient to expel Nature, there will be no returning to the "status quo ante."

Whatever view we may adopt as to the fellah's infallibility in matters agricultural, it seems to be generally admitted that it is profitable for him to be kept somewhat short of water for his cotton crop. But, of course, there is a happy mean somewhere between too much and nothing at all. Apparently the limit of sufficiency was left high and dry in the summer of 1900. Then, to save the cotton crop, the interests of the rice crop were disregarded, and a most carefully prepared programme of distribution was laid down to meet the requirements of the cotton crop only. The river levels were so unprecedently low at the season of cotton sowing that widespread apprehension of general failure of supply prevailed. At one time it appeared as though this feeling might unduly restrict the area planted, and an official note of encouragement was published to inspire confidence in the capacity of the Irrigation Department to deal with the situation. If, instead of a notice in the *Official Journal*, a sermon from the pulpit had been the channel for communicating encouragement to the timid sowers, the modern preacher would have chosen his text from the Preacher of old.

> "Cast they bread upon the waters: for thou shalt find it after many days.
> He that observeth the wind shall not sow; and he that regardeth the
> clouds shall not reap."

Apparently the encouragement prevailed and the bread was cast upon the waters; for, after the crop was in the ground, it was eventually stated as the generally accepted estimate that the area planted with cotton exceeded that of previous years by 8 to 10 per cent, as some of the rice lands were put under cotton. All seemed promising until some time after the flood had risen and the scarcity of water had ceased. Then came mists and inclement weather in September, and the fair prospect was marred. Still, the figure for the crop (close upon 5½ million kantars) is higher than any crop previous to 1896.

It would seem, then, that the yield of the cotton crop is less affected by the variation in the quantity of the river discharges than it is by the weather that prevails during the season when the bolls are maturing, and by the prevalence of the cotton worm which has no regard for the fellah.

It scarcely seems likely that the area planted with cotton can undergo further extension, until the Aswân storage reservoir has been some years in working order, and more land has been reclaimed as a consequence. So it is probable that, given a water supply that is not insufficient during the growth of the plant, an absence of cotton worm during the blossoming, and favourable weather for the maturing of the bolls, a yield of from 6 to 6½ million kantars may be expected, but scarcely much more.

The cotton crop is the most important of Lower Egypt's crops in that it is its main source of wealth. Next to the cotton crop in importance comes the maize crop, important as the poorer people's food supply. Before the Barrage became efficient, the ground was not prepared for maize sowings by the usual system of shallow inundation until the commencing flood had raised the river levels considerably. But already in 1887 it appears that the date of sowing had commenced to advance. In a paper by Mr. Willcocks on "Irrigation in Lower Egypt," read on the 22nd February 1887 at the Institution of Civil Engineers, is this passage:—

"The regulation of water for summer irrigation is thrown into great confusion, about the 15th July, by the cultivators on the summer canals taking water for their maize before the flood has really come. Flood irrigation, properly speaking, begins when the water is high enough to flow into the flood canals, which ordinarily takes place about the first week of August. Not satisfied with waiting for the flood, the larger cultivators on the summer canals, from about the 15th July, work their engines and water-wheels night and day, while the smaller ones turn out with kerosene tins worked as shadoofs, and a dozen other contrivances, to irrigate their lands and put in maize. Since the area under irrigation is trebled, while the supply of water at the heads of canals is unaltered, there results, as a natural consequence, a very serious deficiency of supply at the tails of the canals."

Such is the record of the situation in 1887. Since then, in consequence of the improvement of the summer supply caused by the Barrage's increasing efficiency, and also because of a frequency of years of favourable river discharges, the custom of sowing maize in July has spread from the comparatively few to the many, and the date for commencing has advanced still earlier, so that the first sowings now begin in June. At the same time, and following on the same causes, the cotton area has increased to such an extent that the total yield has almost, if not quite, doubled since 1887. And so it has come to pass that, in a year of bad summer supply, it is found necessary to forbid the planting of maize until the flood has risen sufficiently to allow of it, in order to save the cotton crop from perishing of drought. The climax was reached in 1900, when, consequently, a Decree was issued forbidding, for that year, the commencement of maize sowings until the Ministry of Public Works should permit it. Within the Irrigation Service this measure was unanimously recognised as an absolute necessity: outside of it there were many that criticised it as a despotic and uncalled for interference with the liberty of the farmer to plant when and what he likes. And an unsuspected change, which had accompanied the adoption of early sowings, was brought to notice. It seems that, when, some years back, the maize sowings commenced in August, the seed sown was that known as "durah shami": but when early sowings became more general, a new seed, known as "durah Americani," was introduced and was gradually substituted for the "durah shami." The American variety requires a longer period to reach maturity than the "shami" variety, and so the postponement of the time of sowing to the usual date of twenty years ago would mean the loss of the crop of the new variety, or at least a serious diminution of its yield. Fortunately, by July 1900, the New Weirs were so far advanced towards completion that, by temporary expedients, it was found possible to conduct the regulation of the Barrage as if the Weirs had been fully completed. And so, when the river at Cairo began to rise towards the end of July, the upstream level of the Barrage was brought rapidly up to R.L. 15·50 and all the canals were fully opened. With the discharges due to this level, the supply is sufficient to put in the maize crop rapidly without endangering the cotton.

It is not to be expected, in view of the approaching completion of the Aswan reservoir, that we shall have in future worse conditions of summer supply than those of 1900. As, then, the maize crop of that year was above the average, it may be considered that the Barrage with its Weirs has now made it possible not only to bring the cotton safely through a year of exceptional scarcity of water, but also to meet the demands made in the interest of the maize crop in such a sufficient manner that this crop also shall not suffer.

Moreover, the expense of raising these crops has been lessened: for the delivery of the water at a high level to the lands irrigated by the canals, which draw their supplies from above the Barrage, has caused a large saving in cost of lifting and in coal expended for working steam pumps. Even the partial use of the Barrage in 1884 caused, according to the Railway returns, a falling off of 12,000 tons of coal supplied to the six principal towns of Lower Egypt during the first seven months of the year, and this in spite of the fact that many steam pumps use cotton stalks as fuel instead of coal.

Another end gained by making the Barrage efficient was the avoidance of the necessity of adopting the alternative costly project of pumping stations, the working of which, as has been already shown, would have burdened the country with an annual expenditure of £E.248,500, whereas the yearly cost of maintaining and regulating the Barrage is about £E.10,000.

Again, the raising of the water-level above the Barrage, combined with measures to maintain the Rayyah Beherah in an efficient state, (which have also been a great success,) resulted in the Province of Behera being given a better supply by flow than the pumps at Khatatbeh and Afteh, referred to before, could give by lift. So these pumps were no longer required and the expense of pumping was therefore economised. From 1886 to 1889 this pumping had cost the Government annually from £E.80,000 to £E.90,000, made up of a yearly subsidy of £E.26,320 and the remainder as payment for water lifted, calculated at the rate of £E.42 per million cubic metres.

As far as the fellaheen of Egypt are personally concerned, the greatest advantage gained by raising the water-level at the off-take of the main canals has been an enormous decrease in the quantity of silt clearance. This decrease has permitted of the abolition of the Corvée, and made it possible to maintain the canals by paid labour working under contractors. The amount expended in Lower Egypt on the work formerly done by the Corvée is now under £E.200,000. For this expenditure the necessary maintenance works are executed in a more satisfactory manner than was ever done by the unwieldy Corvée, canals are remodelled and some new works carried out every year. The number of unpaid labourers turned out to clear canals and repair banks in Lower Egypt (excluding Gizah) in 1883 was equivalent to 106,616 men, working for 100 days. In 1884 it was 88,299. Taking a man's labour per diem as worth 4 piastres (1 franc), this labour was worth £E.426,466 in 1883 and £E.353,196 in 1884. And moreover, with these numbers, the work that was necessary was never completed, and remodelling and new works had become out of the question. For not only were the nominal numbers insufficient, but the actual numbers were still more so. In 1885 the Inspectors of Irrigation reported that the Corvée would not turn out: and naturally, for the koorbash had been abolished, and no inducement had been substituted for it. Thus, the koorbash being abolished, it became necessary to substitute paid for unpaid labour, and this was only made possible by the economy in the maintenance charges of canals effected by the restoration of the Barrage.

Huxley, in one of his "Lay Sermons, Addresses and Reviews" has this passage:— "it is to be feared there are naturalists in existence who look upon geology as Brindley regarded rivers. 'Rivers,' said the great engineer, 'were made to feed canals.'" The statement may be considered by less enthusiastic votaries of irrigation to be a little too comprehensive, but, if its application be limited to the river of Egypt, it cannot be said that the actual purposes which the river is made to serve belie the assertion. Whatever may have been the purpose for which the Nile was made, it is certain it is now being compelled to feed canals all the year round, and in summer to do nothing else. For, as it has been pointed out, the efficiency of the new closing gates, fitted to the Barrage, has made it possible to utilise the full discharge of the Nile during a bad summer, and to turn *all* the water into the canals for irrigation purposes; and the construction of the new Weirs has added a further development to its efficiency by making it possible to take full advantage of the first increases of the commencing flood. But, with these gains, disadvantages are connected: the Nile Branches below the Barrage are rendered unnavigable, and salt water travels up the branches from the sea. To meet the first disadvantage, some of the principal canals have been made navigable by the construction of locks; and to meet the second objection, the canals in the north of the Delta have been connected-up with those fed from above the Barrage, so that irrigation and drinking water is provided by them to those villages and areas, which formerly obtained their supply in summer direct from the river.

The one great objection to the high-level water obtained by regulation on the Barrage is the danger of damaging lands by infiltration. This has actually taken place in some situations. The remedy appears to be a more complete system of drains and a more plentiful supply for washing the lands. Money has been at length obtained both to dig the channels which will improve the drainage, and to make a storage reservoir which will to some extent improve the summer supply of water required for washing the salt out of the lands.

There is one other objection urged to the Barrage, but it is a fanciful one. It is accused of creating above it a stagnant pool, which is said to be injurious to the health of the dwellers in Cairo. This accusation has been made chiefly on the authority of one or two misinformed medical men, who adopt the *post hoc propter hoc* system of reasoning. Through what is loosely termed a "stagnant" pool the whole Nile flows past Cairo in a channel of no great dimensions. The average minimum discharge of the Nile in summer may be taken to be 30 million cubic metres a day, or 347 cubic metres a second. To call a channel of 2,700 square metres, through which such a discharge passes, a stagnant pool, is to employ a misnomer; and to consider that the reduction in the velocity of the flood, due to holding up at the Barrage, is a cause of serious danger to the health of Cairo is to show a want of appreciation of the general sanitary condition of the capital of Egypt. If the inhabitants can live in the atmosphere and under the conditions that all but a favoured few do in Cairo, they are not likely to be affected by the fact that, instead of the river flowing past the town at the mean rate of 14 kilometres a day, it flows at the rate of 11 kilometres a day, the former rate being the mean velocity at lowest Nile with the Barrage open and the latter with it closed. The calculation of these velocities is made from a cross-section of the river taken just south of Gezireh Palace.

There is then, very little to be said to the discredit of the Barrage but how much is there to be laid to its credit! It has doubled the cotton crop, which is now worth twelve million pounds, and thereby secured the wealth of Lower Egypt. It has provided for the timely sowing of the maize crop and thus ensured to the people its food supply. It has lessened the cost of raising both these crops and so enriched the people. It has largely protected Lower Egypt from the effects of the lowest flood on record and by so doing secured the revenue and the crops. It has enabled the Government to substitute contract work for the scandal of the Corvée, and to acknowledge in a practical way that the labourer is worthy of his hire. Judged by its performances it is a work to be proud of. The original conception of the project, to whomsoever it may belong, was a grand one. It was to the haste with which the work was fitfully urged along, that the early failure must be charged. Never was there a better illustration of "More haste less speed." For the work, that was commenced in 1843 and to which the stimulus of Mehemet Ali's impatience was applied in 1847 with fatal results to the Rosetta Barrage foundations, was still far from complete in 1853, as we see from the record of the state of the Rosetta Barrage in that year, left us by Linant Pasha. (Plate II). The Barrages were supposed to have been completed in 1861, but even then they had not been fitted with half the full number of gates. They had thus taken eighteen years to construct. Now, compare this with the record of the construction of the Assiout Barrage, which is almost as large as the two Delta Barrages combined, and has had to be built as one work across the undivided river. The preliminary work began in April 1898. Actual masonry began on 4th May 1899, and the Barrage will be finished by April 1902, that is, in four years from the commencement of the first preliminaries. The work has not been unduly hurried, and its foundations have most unquestionably been laid with greater care and are more trustworthy than were those of the older work.

We now know how bad the foundations of the first Barrage were, and can appreciate fully the courage of the attempt to restore the work in the face of the condemnation that was universally pronounced against it. The warnings of the cautious would have had it left alone to be a monument of confessed failure, and a witness, so long as it should stand, of the impotence of the present age within full view of the enduring Pyramids of a more robust past. But the Barrage fell into the hands of men, whose experience taught them to be bold without being rash, and who, having confidence in themselves, ventured what more timid men would not take in hand, in order that the country might win much by their successful daring, and the standing reproach of a useless Barrage be taken away from the builders of the nineteenth century.

Contrast the effects of what was done under their able direction by the expenditure of half a million pounds on the Barrage with the results of the reckless ill-spending of ninety millions when Ismail was Khedive. The borrowing and spending of the larger sum brought the country to the verge of bankruptcy; the later comparatively small outlay helped largely to convert the condition of Egypt from pauperism to prosperity. To these men then, who made the feeble strong and gave the thirsty to drink, the land of Egypt owes a deep debt of gratitude: inasmuch as the Barrage at the Head of the Delta has been one of the chief instruments that, by skilful handling, has helped to bring about the regeneration of Egypt.

But it no longer holds the proud position of being the largest irrigation work in Egypt. The Aswân dam and the Assiout Barrage have put it in the third place so far as magnitude of single separate works is concerned; but yet I think it must be admitted that it still holds first place in point of importance. Of these three fine works, the Delta Barrage is the one that could be least spared, and it alone, so far, has a record of honourable service, rendered during the closing years of the nineteenth century.

"Just a hundred years ago Egypt was lying politically and commercially dead under the indolent *régime* of the worthless Mamelukes," Mr. Cameron remarks in his "Egypt in the Nineteenth Century." And what is its condition *now*, and what is the promise of its future! There is no need to describe here the rapid growth of its prosperity during the latter part of the century. Lord Cromer's Annual Reports are the official and the best records of that growth. As for its future, Mr. Cameron, at the end of his book just named, indulges in the pleasant performance of prophesying smooth things for Egypt. The spirit of prophecy came upon him in the year 1898, and it would seem now, three years later, that he bids fair to become a true prophet. His book closes with this vision of the future:—

"Egypt is a land of promise, a country with a great future in the twentieth century. The Nile will have been opened up from Nyanza to the sea. We shall have railroads and steamers through the heart of the Soudan, the canal will revert to the State at the end of the concession in 1969, the public debt will have been reduced to moderate dimensions, and, for its size, the province of Egypt will have become the most valuable domain on the face of the globe."

Since this prophecy was penned, the battle of Omdurman has been fought and Khartoum, with the Soudan, recovered: a waterway has been cleared through the "Sadd" above Fashoda; the Aswân Dam and the Assiout Barrage have been begun and all the difficult work completed; the Ziftah Barrage has also been commenced. These reproductive works will be followed by others at short intervals, and prosperity will breed prosperity, until the prophecy is fulfilled and Egypt becomes, for its size, "the most valuable domain on the face of the globe."

Nor will the proverb for Egypt be that of the land of Israel:—"The days are prolonged and every vision faileth;" but rather: "The days are at hand and the effect of every vision."

(EZEKIEL XII, 22, 23).

# PLAN OF THE BARRAGE

SCALE = 1 : 40,000